AERIAL PHOTOGRAPHY AND MULTISPECTRAL REMOTE SENSING FOR ENGINEERING SOILS MAPPING

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BY

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PROGRESS Report

AERIAL PHOTOGRAPHY AND MULTISPECTRAL REMOTE
SENSING FOR ENGINEERING SOILS MAPPING

To: J. F. McLaughlin, Director
Joint Highway Research Project

May 6, 1969

File No. 1-4-21

From: Harold L. Michael, Director
Joint Highway Research Project

Project No. C-36-32U

The attached report entitled "Aerial Photography and Multispectral Remote Sensing for Engineering Soils Mapping," completes Phase B of the project entitled "Annotated Aerial Photographs as Master Soils Plans." This report was prepared by Marc G. Tanguay, Graduate Instructor in Research under the direction of Professor Robert D. Miles.

It is concluded that color aerial photography is the best and most reliable source of information for the interpretation of soils and soil conditions. For soils engineering maps at a scale factor of 400 feet per inch, it is estimated that the cost of preparation is about $75.00 per linear mile using color transparencies. For comparison it is estimated that black and white photography would cost about $87.00, color positive prints about $89.00 and color infrared transparencies $76.00.

The report is submitted to the Board for the record and for acceptance as fulfillment of the objectives of the research.

Respectfully submitted,

Harold L. Michael

Harold L. Michael
Associate Director

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AERIAL PHOTOGRAPHY AND MULTISPECTRAL REMOTE SENSING FOR ENGINEERING SOILS MAPPING

Phase B

by

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Project No.: C-36-32U
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Conducted by

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ABSTRACT

Tanguay, Marc Gilles, Ph.D., Purdue University, June 1969. Aerial Photography and Multispectral Remote Sensing for Engineering Soils Mapping. Major Professor: Robert D. Miles.

This research investigated color aerial photography and other remote sensing techniques including multispectral imagery and their application to engineering soil mapping. The principal objectives were to study the incremental gain in information through the use of these techniques and to determine the cost savings if any.

Other objectives included (1) the investigation of some of the variables influencing the reflectance of materials and their diurnal thermal behavior, as it affects thermal imagery; and (2) the generation of engineering soils maps by computer analysis of digitized multispectral data.

A test corridor was selected from Indianapolis southwest to Bedford. Coverage of this 70-mile long section was obtained with various types of aerial films at a 1:4,800 scale ratio (black and white, black and white infrared, color and color infrared) and with multispectral imagery. The multispectral data was obtained in 15-wavelength bands ranging from ultraviolet to thermal infrared in the form of film strips and corresponding analog tapes. These tapes were converted to digital data for computer analysis.

Laboratory investigations included spectral reflectance of characteristic soil and rock samples. Field investigations included infrared

radiometer readings, temperature and moisture measurements at different test sites, and diurnal apparent temperature measurements obtained for periods of 24 and 48 hours for characteristic materials.

Major conclusions reached by this research are:

(1) Color photography was found to be the best and most reliable source of information for developing detailed engineering soils maps using annotated aerial photographs.

(2) The multispectral imagery is a source of information on soil conditions to supplement color aerial photography. Four to six judiciously selected wavelength bands seems an adequate maximum number of bands for visual interpretation because of human limitation at studying great numbers of grey toned areas.

(3) The maximum information from the multispectral imagery was obtained by computer classification which permitted (a) classification of terrain into general classes of soils, vegetation, forests, water, roads; (b) preparation of computer maps of up to seven soils based on the spectral response, with unique soils singled out to emphasize distribution of adverse soil conditions, (c) and maps that show spectral relationship between soil and its land form and between soil and its source.

(4) Based on field measurements of thermal infrared radiation, color, moisture, cloud cover and wind controlled materials surface diurnal temperature variations. Moisture was the most important factor. Peak temperatures showed some differences among the investigated materials. However certain of these materials could not be separated on the basis of peak temperatures alone, although they

were quite different in nature. Color proved to be more important than texture in the overall thermal behavior. The 8-14 micron region appears useful in separating soils relative moisture content but inadequate in determining other characteristics.

(5) Detailed engineering soils plans and profiles prepared by interpretation of color aerial photographs can be successfully incorporated into highway soil surveys. They can be used to plan better soils investigations and to select boring locations so as to obtain more representative samples. The additional expense for color photographs is offset by the economies resulting from their use during the preparation of detailed maps for highway soil surveys.

CHAPTER 1

INTRODUCTION

It is appropriate to reconsider engineering soil mapping methods so as to incorporate recent developments in aerial color film technology and remote sensing techniques by means of multispectral aerial scanners. This thesis describes an investigation on the use of several types of aerial photography supplemented with multispectral remote sensor imagery.

This research is a part of project (C-36-52U), called "Annotated Aerial Photographs as Master Soils Plans for Proposed Highways", and is a cooperative research effort conducted by the Airphoto Interpretation and Photogrammetry Laboratory, Joint Highway Research Project, School of Civil Engineering, Purdue University. Jointly financed by the Bureau of Public Roads and the Indiana State Highway Commission, the project was initiated on April 20, 1965 and will terminate on June 30th, 1969.

The project has a two-fold purpose, and accordingly was divided into two phases. The first phase (Phase A) evaluated multispectral photography and imagery to determine the best system or combination of sensors to be used for the development of soil plans in highway engineering. Phase A was completed during the period April 1965 to January 1967. The final report for Phase A was prepared by Rib and distributed in 1967 [211].*

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*Numbers in brackets refer to items in Bibliography.

1.1 Purpose of Study

This report describes the work undertaken in the second phase (Phase B) of this project. Phase B was planned to further test and more extensively evaluate the system of sensors recommended in Phase A by preparing engineering soils strip-maps of a selected highway project.

The purpose of this research is the preparation of more economic and more reliable plans and profiles of the layered soil system at or near the surface of the ground. Such detailed engineering soil plans and profiles aid the highway engineer to design a more efficient and representative sampling program so as to determine more accurately the field conditions and thus to produce a better design and to more reliably and more consistently anticipate problems affecting construction, performance and economy. The plans prepared by aerial reconnaissance are not intended to replace the conventional ways of sampling and classifying earth materials but simply to improve the method and hopefully to reduce costs by making the selection of boring locations a more discriminative process.

1.2 Scope of Study

In phase A of this project, Rib studied several combinations of different types of aerial photographs and multispectral, infrared and radar imagery in order to select a combination that would best permit an analysis of soil conditions.

He concluded that the system yielding a maximum of information and involving a minimum of field checking is one which simultaneously obtains multichannel imagery and natural color aerial photography. The multichannel system should provide spectral information in a minimum of seven

bands of the electro-magnetic spectrum: ultraviolet, violet-blue, green, yellow-orange, photographic infrared, middle infrared (3.0-4.0 microns) and far infrared (8.-14. microns).

For the case where a multichannel system is not available, Rib concluded that the maximum of information would then be obtained by a combined system taking simultaneously natural color photography and color infrared photography with adequate filters for enhancement of the soils. In the case where only one film can be used, he recommended natural color as the best film for mapping soils.

The scope of Phase B is as follows:- 1) to prepare by remote sensor systems a detailed master soil plan for a highway project, 2) to apply, re-evaluate, and possibly improve the mapping procedure proposed in Phase A and 3) to investigate the cost of such an approach.

1.3 General Procedure

The area under study is a 70-mile stretch of State Route 37 from Indianapolis to Bedford, Indiana. Figure 1 shows the route selected. It was selected on the basis of greater variability of earth materials and land forms. The principal physiographic units encountered and the general geology are illustrated on Figure 2.

Intermediate scale aerial coverage with black and white Kodak Plus-X panchromatic film was obtained April 11, 1967 by the Indiana State Highway Commission (ISHC) plane. This produced a basic set of 1:12,000 scale photography of the entire route for planning the field data collection procedures and the future multichannel flights.

In order to obtain remote multispectral imagery, authorities of the U.S. Department of the Navy Office of Naval Research and the U.S. Army

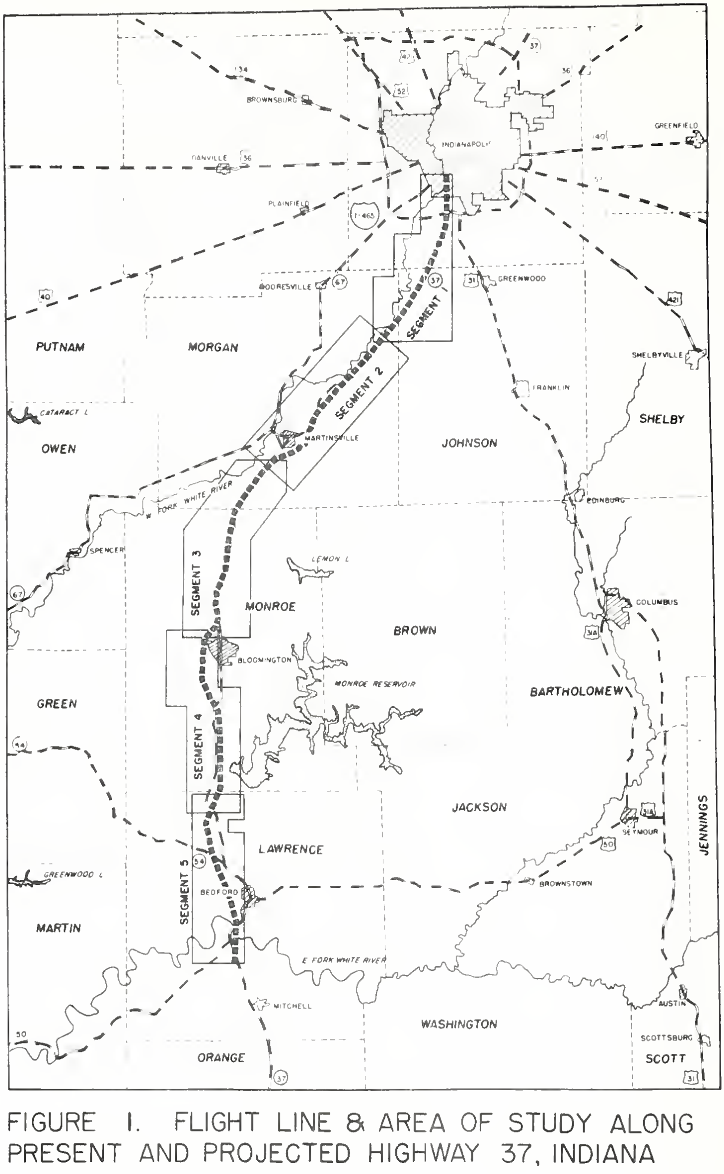

FIGURE I. FLIGHT LINE & AREA OF STUDY ALONG PRESENT AND PROJECTED HIGHWAY 37, INDIANA

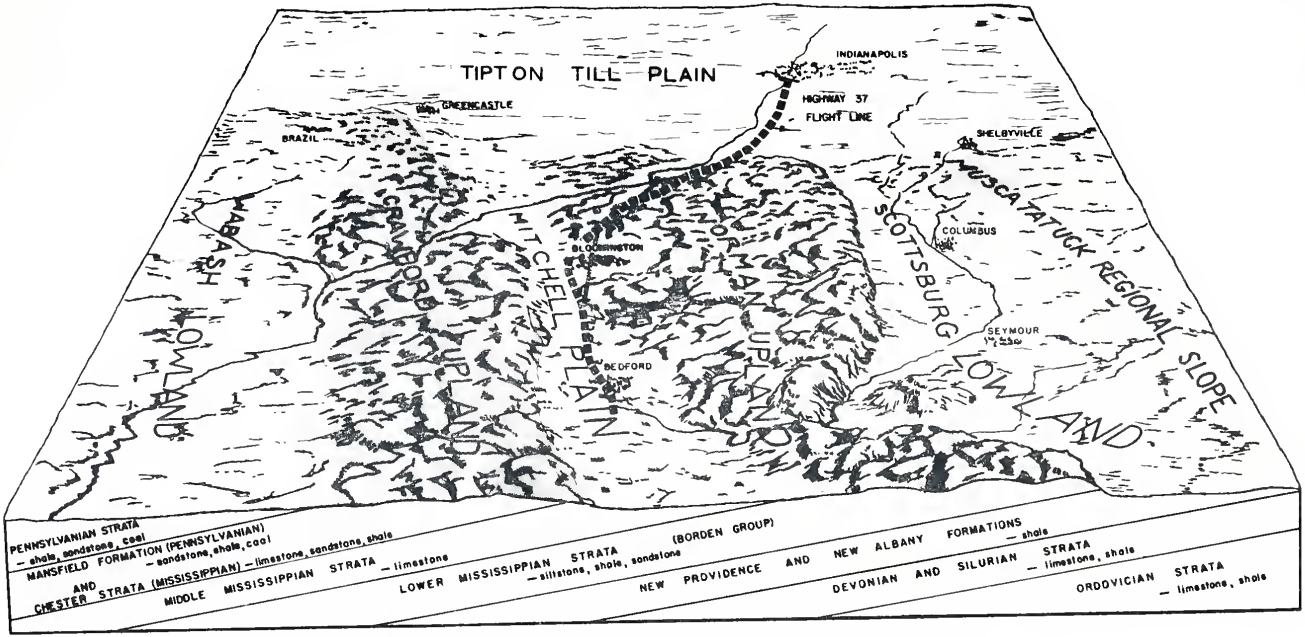

FIGURE 2. PHYSIOGRAPHIC UNITS AND HIGHWAY 37 FLIGHT LINE

Electronics Command were contacted to use the Project Michigan M-5 scanner. With the assistance of the Bureau of Public Roads as the designated user, permission was granted to use this classified* equipment.

The multichannel data collection flight took place on April 28, 1967. The Project Michigan aircraft operated by personnel of the Willow Run Laboratories, the University of Michigan, flew over the designated area collecting information in fifteen different narrow bands of the electromagnetic spectrum.

0.32 - 0.38 micron	0.58 - 0.62 micron
0.40 - 0.44	0.62 - 0.66
0.44 - 0.46	0.66 - 0.72
0.46 - 0.48	0.72 - 0.80
0.48 - 0.50	0.80 - 1.0
0.50 - 0.52	4.5 - 5.5 microns
0.52 - 0.55	8.0 -13.5 microns
0.55 - 0.58	

Personnel of the Indiana State Highway Commission (ISHC) took all the aerial photography for this project. They used a 6" focal length Wild RC-8 aerial camera mounted in a single engine aircraft. Table 1 summarizes the series of flights, films and filters and other conditions pertinent to the photography and imagery collection.

Prior to the multichannel flights, several days were spent in the field collecting data concerning (a) the moisture conditions of soils, (b) direct temperature readings on soils, and (c) the apparent temperatures of soils and rocks by means of a Barnes PRT-4 infrared radiometer.

The maximum information obtained in one day was on April 28, 1967, when the multispectral scanner collected the multispectral imagery in

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*In a letter dated December 28, 1967, issued by the Security Classification Management Division, Office of the Assistant Secretary of Defense, the imagery obtained from the Project Michigan M-5 scanner was declassified.

TABLE 1. PHOTOGRAPHY AND IMAGERY DATA SHEET

Project: Indiana HPR Part-1 Location: SR-37, Indianapolis to Bedford

Date and Instruments	Alt. (ft.)	Time start	Time end	Speed	F stop	Mean terrain	Approx. scale	Film types
4/11/67 RC-8 (6")	6700	-	-	-	-	700'	1:12000	Plus-X Pan (1 roll)**
4/28/67 Scanner*	3200	10:55 (going south)	11:38	-	Cone	700'	1:28800	Multispectral
4/28/67 Scanner*	1600	11:48 (going north)	12:35	-	Cone	700'	1:14400	Multispectral
4/28/67 RC-8 (6")	2400	9:55	12:18	200	6.8	700'	1:6000	#SO-151 (3 rolls) No Filter
5/18/67 RC-8 (6")	2400	9:50	12:35	200	8.0	700'	1:6000	Plus-X (1 roll) #8442 (blank) No Filter
5/19/67 RC-8 (6")	2400	9:40	12:00	200	6.8	700'	1:6000	#8442 (3 rolls) No Filter
5/22/67 RC-8 (6")	2400	12:40	13:06	200	6.8	700'	1:6000	#8443 (2 rolls)** Antivignetting Wratten 12
5/24/67 RC-8 (6")	2400 2400	10:05 11:35	10:32 11:42	- -	8.0 8.0	700'	1:6000	#8443 (2 rolls)** Infrared BW (4 rolls)
5/25/67 RC-8 (6")	2400	11:00	11:30	-	8.0	700'	1:6000	Plus-X (1 roll)** (rerun)

*Multispectral scanner M-5 serial No. 27206, Project Michigan, Willow Run Laboratories, The University of Michigan.

**Except for films SO-151 and Ektachrome type 8442, all films were exposed with an antivignetting Wratten 12 filter.

fifteen separate bands and at two different altitudes and when the ISHC personnel took three rolls of Ektachrome MS Aerographic film (estar base) type SO-151. This film is now replaced by the film type 2448 and will now be referred to as such.

After receiving the prints, films and imagery, mosaics were assembled and engineering soil maps prepared. At first, a regional engineering soil map at a scale ration of 1:20,000 using U.S. Department of Agriculture photographs was prepared to provide an understanding of the regional distribution of land forms and parent materials and allowed for a more accurate interpretation of the larger scale sample sections. In all, nineteen different photo-maps were interpreted either from black and white, color or color infrared films and prints.

The multichannel imagery was investigated in three different ways:-

1) by visual means aided by magnifying tools,
2) by densitometric measurements on negatives, and
3) by computer analysis and the methods developed at the Laboratory for Agricultural Remote Sensing (LARS) at Purdue University.

In order to better define the role of remote sensing methods in engineering soils mapping, the following sections of this introductory chapter are concerned with the development of engineering soils maps. Chapter 2 briefly reviews the pertinent literature concerning the different methods of obtaining information on soils and rocks by remote sensors. Chapters 3 and 4 discuss the results of the research under Phase B and describes the types of detailed engineering soils maps prepared. Chapter 5 is a cost study of the method used for mapping soils as

compared to conventional means. This is followed by the conclusions and recommendations.

1.4 The Development of Engineering Soils Maps

Engineering soils maps can be defined as an expedient for the presentation of soil information in terms of engineering uses. Jumikis et al. [117] have defined these maps in the following manner:

> "The engineering soils maps were designed with the needs of the civil engineer specifically in mind. Containing the most recent scientific data available on the engineering materials of New Jersey, presented in standard form, using modern techniques of investigations, they focus in one place much information drawn from related sciences and correlated from an engineering point of view."

Pedological maps are useful sources of soils information for the engineers [245]. Where pedological maps are not available or where no pedological survey has been conducted because of non-agricultural developments, engineers rely on some other source of soils information for their planning. Topographic maps and geological maps, when available, certainly help but are not ideal.

With greater availability of aerial photography and by use of the technique of airphoto interpretation, the preparation of materials surveys and maps for each engineering project became possible.

Engineering soils maps can be prepared in various ways. The three principal approaches are (1) to use pedological maps and a knowledge of the soil series classification, or (2) to use aerial photographs and photointerpretation techniques, or (3) a combination of both. The geological maps generally are not used as a sole source of information, but often complete the information from the other sources.

The steps to prepare engineering soils maps and some indication as to their content has been presented by Belcher [19, 20, 21]. The concept of soil pattern was also discussed and the engineering significance of soil patterns was defined [22, 24, 25]. The concept of land form and its importance for the inference of engineering soils characteristics also was pointed out. These concepts, partly borrowed from Geomorphology, are an important part of the airphoto interpretation concepts.

Illinois, Michigan, Kansas and Nebraska have used pedological maps to correlate with engineering characteristics of soils. It is claimed that the end-result is obtained much faster, in a more reliable manner and that it has a higher engineering significance.

The second group of states, where airphotos are the primary sources of information, does include: Indiana, New Jersey, New Hampshire, New York, Rhode Island, Maine, Ohio, and also countries like Canada and South Africa.

Frost pointed out the uses of airphotos for granular materials surveys [78]. He described the role of photo-interpretation in the study of soils [79] and the factors limiting the interpretation [80]. In 1943, Belcher, Gregg and Woods published information for the preparation of engineering soil maps. Their book on, "The Formation, Distribution and Engineering Characteristics of Soils" was meant to bridge the gap between the use of pedological information, land form patterns and the engineering properties of the most common soil series [27]. The technique of systematic interpretation of aerial photographs was used in order to prepare a detailed drainage map of Indiana and also to produce engineering soils reports and maps for the different counties, or for

special projects. The work of Parvis [202, 203], Miles [165, 166, 167], Mollard [180], Montano [183], Frost and Woods [83], Frost et al [82] is acknowledged.

In other states, the preparation of engineering soils reports had progressed too. Moultrop [187, 188] made major contributions in this field, for the State of Rhode Island. His work is an excellent example of typical engineering soils mapping and the mapping technique and symbolism developed are among the most useful.

In Main, Stoeckeler [231, 232] has contributed in using more of the geological information available for this state. He pointed out the importance of appropriate scale for the photos and for the maps.

In New Jersey, Lueder [147], Holman, McCormack, Minard and Jumikis [102, 103] contributed in developing a new symbols system for coding of the engineering soils map. This system is based on assembling letters and numbers into a composite symbol that describes the land form, the texture of the soil and indicates some other engineering property like the approximate depth to the water table. Lueder [147] insisted on the importance of the pedology and pedogenesis of the soils, as the evolution of soil profiles is controlled by factors like the climate, parent material, time, topographic position and biologic factors.

In Ohio, Mintzer and Struble made comparative studies, with cost analysis, on the different materials survey methods, by aerial photo interpretation, geophysical methods and the standard investigation methods of bore holes and test pits, and combinations of these methods [177, 178]. They concluded that a combined technique, using airphoto interpretation, some geophysical investigation and a minor amount of

bore holes is the most economical approach to investigate soils for engineering purposes. The combined method was found to cost one third of what the conventional approach would cost.

In South Africa, Brink and Williams [34, 35] prepared several engineering soils maps. In Canada, Mollard has used aerial photographs in the production of earth materials reports [180] and in engineering geology applications [181, 182]. Other persons also contributed to this field: Seymour [222], Parkinson [201] and most particularly Sen Mathur and Gartner [221]. Their Ontario Department of Highways publication contains numerous well illustrated cases and presents a series of useful tables on the engineering significance of materials as related to land forms.

1.41 Methods of Preparation of Engineering Soils Maps

The procedures and methods of making engineering soils maps using pedological soil surveys information and aerial photographic interpretation techniques are summarized below.

1.411 Pedological Information as a Source. When preparing an engineering soils map from published agricultural soils information some assumptions are made: (1) the scientist or engineer involved must have a working knowledge of both pedological and engineering nomenclature and (2) the premise of uniformism has to be accepted.

A minimum of field correlation is required to determine by means of bore holes (generally hand auger borings and available natural or man-made cuts) and also by means of samples collected for either field or laboratory testing, the characteristics of the soils and then classify them according to standard methods.

It also is assumed that the land form-parent material relationship is valid [19, 21, 169]. It is accepted that under a given set of parameters like climate, vegetation, parent material, time and topographic position, a given parent material will result in a given soil profile, [27, 147, 169].

Some work has been done on correlation between soil series and engineering significance. For the state of Indiana, two principal sources are available: "The Formation, Distribution and Engineering Characteristics of Soils" by Belcher, Gregg and Woods [27] and a more recent unpublished work on "A Regional Approach to Highway Soils Considerations" by Lovell and Sisiliano [142].

For the state of Michigan, a "Manual for Engineering Soils" has been prepared (1946) and revised in 1954. It represents the principal source of information for correlation purposes in that state. Other states have similar manuals such as the Soil Manual for the State of Washington by McLerran.

A limitation inherent to the pedological approach is that the interpreter does not obtain a "true vision" of the ground as is the case in the aerial photography approach. For instance, the overall drainage of an area is not reflected on the pedological map in a manner which could help the interpreter to attach engineering significance. The degree of saturation of the soil or the poorly drained areas, will not be detected either.

Furthermore the pedological information is given in terms of the surface horizons. In most cases, little or no information is given on the parent material: this is the horizon of greatest importance to the

engineer. In the same manner, the pedological map generally will not reveal much about the depth to bedrock, potential landslide areas, or sources of granular materials. Obviously all these limitations have to be overcome. In practice there are two alternatives; one is to conduct extensive field checking, the second is to use other sources of information like aerial photographs, geological maps, well logs or other shallow boring logs, geophysical investigation and systematic boring investigation.

1.412 Aerial Photographs as a Source. This approach also necessitates certain assumptions. The investigator must be competent in photo-interpretation and ideally have a solid background in the earth sciences (particularly geomorphology) and in civil engineering (particularly in the elements of soils mechanics). It also assumes the validity of the close relationships between land form and parent material; in other words, it assumes that soils derived from the same parent material and submitted to the same environmental conditions would have similar engineering properties.

The preparation of engineering soils maps thus becomes more or less a well established routine. The principal steps to follow are listed below, in a simplified manner [42, 147, 148, 103, 187, 188].

(1) literature survey of earth materials information available for the area

(2) acquisition of adequate aerial photographic coverage, with a minimum of 60% overlap and 30% side lap.

(3) assemblage of photos into mosaics of alternate prints

(4) photo-interpretation

(5) field correlation; soil sample testing; preparation of soil profiles

(6) correction of interpretation

(7) tracing of maps; plans and profiles; report.

The mosaics present some problems because most of the time uncontrolled mosaics are used. The much higher cost of semi-controlled or fully controlled mosaics does not allow for their use. On this matter, the advent of orthophotomaps may be of great help [3] although expensive. At the present time, topographic maps and county transportation highway maps can provide an adequate base for control of the photo-mosaics.

1.42 Field Correlation

This is related to the amount of field work that permits to tie up the interpretation to the present field situation. It can be done in different ways and the amount of time, efforts and monies spent are dictated by the goals at stake. In the case of regional and county engineering soils maps, field examination of the terrain configuration, of road cuts, pits and erosional features accompanied with some bore holes (hand auger most often) constitute adequate sources on which to base the correlation. This is the approach also taken in most detailed engineering soil mapping for separate projects. It is also the approach in this research project. In cases where depth to bedrock is of critical importance, geophysics studies and some drilled bore holes may be required. The amount of field correlation should be based on the amount of details required, the complexity of the terrain and the time available.

1.43 Content of the Engineering Soils Report

An engineering soils report should contain the following information: [187, 214]

1) introduction and general information on the work
2) information on the climatic conditions, description of the physiographic units and subunits and information on the geology of the surficial deposits and bedrock
3) information on the mapping procedure, the type and amount of field correlation, soil sampling and testing
4) explanation of the map units and symbols
5) description of map units and engineering significance
6) bibliography.

1.44 Nomenclature and Symbols

The advantage of using appropriate nomenclature and convenient sets of symbols has been discussed in the literature. A system of coding for the engineering soils maps of Indiana counties was developed some time ago [171, 183]. It has the great advantage of using a minimum of symbols to yield a maximum of information but it may present a problem for the untrained person to read.

Another approach was set forth by Lueder [147]. It was used extensively by other groups [117, 103, 186, 175]. Each soil unit (area of soil with similar characteristics and soil profile) is labelled by a composite symbol. Each composite symbol is broken down into three parts. The first part refers to the land form of the original geologic formation. It is made up of one, two or several letters. The second part represents the soil textural class according to the Highway Research Board soil

classification (also AASHO Classification). It is represented by a number. The last part gives some indication of the drainage characteristics of the soil unit, like the quality of internal drainage and the depth to water table [103]. A similar system was developed for this report.

1.45 The Mappable Unit

The problem of determining what is a mappable unit always comes up at the time of interpreting the aerial photographs or when "translating" the pedology information into engineering terms. Holman et al, [103] and Weeden [253] have adequately answered this question. It should be required for a unit in order to be mapped to be:

(1) capable of a written definition,

(2) positively recognizable by terrain reconnaissance techniques

(3) preferably related to natural occurrence and based on actual conditions and not on factors assumed for convenience

(4) capable of being related to numerical evaluation of physical characteristics controlling highway design, construction, maintenance, drainage, etc.

(5) significantly different from other units

(6) flexible for further subdivision, but number of units should be limited to a minimum in practice

(7) based on a maximum utility

(8) economically justifiable.

1.5 Purposes and Utilization of Engineering Soils Maps

The purposes of engineering soils maps are quite numerous. One can define them primarily as maps showing the areal extent and distribution of earth materials in terms of possible engineering uses. They indicate at various degrees of accuracy and detail (both a function of the source of information and the scale) the areal distribution and location of soils and rocks.

The numerous uses of engineering soils maps are abundantly documented in the literature. A bibliographic survey showed at least thirty different articles, papers and books listing some use. Through this survey, two things were noticeable: (1) the effect of uses upon the scale and (2) the variety of projects and the different stages of a given project at which such maps were being used.

Multiple scales are used and depend upon the amount of detail required. The most frequently used scales for county mapping is one mile to one inch (1:63,360) [103, 261] and half a mile to one inch (1:31,680) [187, 253]. For more detailed work, scales as large as one thousand feet to one inch (1:12,000) or six hundred feet to one inch (1:6000) [177, 178] or even two hundred feet to one inch (1:2,400) [232] are being used.

Generally the small scale maps are prepared from the interpretation of aerial photographs at a scale of 1:20,000 [261] and 1:30,000 [35], or from pedological maps at 1:63,360 or 1:31,680 scale ratios. For the more detailed maps, it is recommended that larger scale photographs be used such as 1:15,000, 1:10,000 or even 1:6,000 [211].

On the basis of types of projects and stage at which the maps are

to be used, the engineering soils map types would be numerous. Many authors have expressed ideas and have quoted projects in which these maps were actually used. The following is a list of the possible uses for highway engineering projects as it was collected from the projects listed on Table 2.

(1) Preliminary investigation and reconnaissance for proposed highways.

(2) Highway planning and design.

(2.1) Materials survey (sources of construction materials)

(2.2) Engineering soils distribution--master soil plans and profiles.

(2.3) Drainage and construction problem areas study

(2.4) Traffic study

(2.5) Construction and maintenance.

(3) Subsurface reconnaissance and boring programs planning for foundations, bridge piers and other structures.

(4) Regional planning and land use evaluation studies.

(5) Engineering geology investigations related to highways and transportation.

1.6 The Accuracy of the Method

Weeden, in writing about the engineering soils mapping methods states:

> --"the majority of the states have successfully related their map units to the AASHO classification, both land form units and soil series, but they have not always been sharply definitive, in many cases quoting a range of AASHO classes" [253, p. 17].

TABLE 2.

ENGINEERING SOILS MAPS: APPLICATIONS

Reference	Project type: Applications	Map or photos scales
Bailey 1958	Highway planning and design: general reconnaissance of route location	1:12,000 to 1:60,000
	reconnaissance of alternate routes	1:24,000 to 1:12,000
	preliminary location surveys and design	1:6,000 to 1:600
	location surveys and contract plans	1:2.400 to 1:240
Blesch & Liang 1962	Railway planning: railway route location, materials surveys, soils and geology, drainage	1:50,000
Brink & Williams, 1964	Highway planning and design: location, design, construction and maintenance phases; mostly for materials surveys and classification	1:30,000
Colwell (editor) 1960 Belcher, Mollard and Pryor,	Highways: location, construction, maintenance and materials surveys. Traffic engineering: vehicle counts, traffic flow Power lines location: shortest alignment for best foundations Pipeline location: depths of soils, water and wind erosion, soft ground and adverse talus and slopes Dam site studies: physiography, materials, geology Flood control structures: materials for dikes and levees, location of structures in terms of physiography, soils and foundations conditions Landslides investigations: areal extend study of causes, possible treatments, and probable future extend and threats to people and or structures	(multiple)
Deacon 1965	Highway planning and design: reconnaissance and feasibility, soils survey, drainage and cultural features, bridges and culverts location, route selection, land acquisition, construction plans and profiles	- NA -
Hicks 1953	Highway design: soils survey for pavement design and past performance	- NA -
Hofman et al. 1961	Highway engineering: terrain conditions and location of adverse areas, soils characteristics correlation with past performance, guide for subsurface investigation, general earthwork and construction materials conditions, borrow materials location	1:24,000
Holman, 1956 Hofman et al. 1957	Highway engineering: location and design, reconnaissance of soils and evaluation, foundations investigations programs, location of borrow materials, pavement design and correlation with past performance, construction problems forecast Airport planning and design Regional and urban planning	1:31,680

TABLE 2 cont'd

ENGINEERING SOILS MAPS: APPLICATIONS

Reference	Project type: Applications	Map or photos scales
Lee 1964	Highway engineering: route location, terrain and soil conditions survey, drainage study	1:63,360 & 1:12,000
Lueder 1959	Route location for highways: preliminary reconnaissance and final location Canals, pipelines, communication lines location Site location for dams, Materials location Water resources studies: water utilization and regulation, sedimentation Coastal and harbors studies Location and assessment of special construction problems, Permafrost studies, Landslides studies (by Ta Liang)	(multiple)
Lund and Griess 1961	Highway engineering: materials location, planning and conducting soils surveys, drainage and runoff characteristics, slope stability studies	- NA -
McLerran 1957	Highway engineering: soils surveys, materials location, general site and route evaluation, potential problem areas, environmental factors	- NA -
Miles 1950 1951 1957 Miles & Spencer 1961	Highway engineering: road location studies, soils and drainage surveys, problem areas determination, sampling locations for more representative survey, pavement performance studies	(multiple) 1:63,360 for county maps and 1:20,000 or larger for detailed maps
Mollard 1949 1962 1963	Highway engineering: granular materials surveys, soil surveys and route location Engineering geology: detailed geological site studies for dams, reservoirs, irrigation systems, erosion problems, ground water studies, sedimentation and flooding	(multiple)
Moultrop 1956 1961	Highway engineering: location and basic design, guide in soils boring programs, location of granular materials, estimate of subsoil conditions, soils conditions in community planning	1:31,680
Rib 1966 1967 1968	Highway engineering: location of construction materials, planning and location surveys, traffic surveys, construction inventory and maintenance, ground conditions: soils depth to bedrock, drainage, plans for boring programs	1:8,000 to 1:15,000

In fact, soil series cannot be sharply defined in terms of AASHO classes because of soils heterogeneity and intermingling of soil layers. This problem of variability was studied by Hampton, Yoder and Burr [91] on two different soil series, Brookston and Crosby, as a function of the different engineering tests; Atterberg limits, grain size distribution, compaction test, Hveem stabilometer test, CBR and unconfined compression tests. They found the soil variability to be a function of the property being tested. Their results indicate for these two soils, a large amount of variability for the different properties. They indicate that a relatively large number of samples per soil series are to be taken in order to determine with reasonable limits of accuracy the engineering properties of these soils. For the Atterberg limits they indicate the horizon and the topographic position are the most important factors of variance respectively.

The amount of borings for reasonable limits of accuracy at a 95% confidence level would be much greater than is accepted even in the conventional highway soils surveys and the cost would of course, be unjustifiable. One then has to compromise. And the question is how much. This has no definite answer. It is a function of economics, of good engineering practice, of the type of structure being built and of a good many other factors. It is important to recall here that engineering soils maps have to be based on sufficient sampling to indicate the broad textural classes of soils using the standard soil classification methods.

It is not economical to bore every two to five hundred feet along a center line, or try to sample every mapped unit. This is precisely where detailed engineering soil maps are of greatest help. Not only

would the maps be of great assistance for the route selection process but also they would

1) assist in developing the soil boring programs.
2) make these programs more representative and reliable because testing would be provided for each significant map unit.
3) avoid duplicating and over-sampling of uniform map units.
4) allow for a much better overall understanding of earth materials distribution over the area and help in the selection of design values for pavements or other facilities [262].
5) allow for other accrued benefits like the minimization of roadcuts and deep fills, fast location of adequate construction materials supply, and an easier and more precise evaluation of drainage needs.
6) minimize the cost of boring programs by a sensible reduction of the total number of borings and also cut the overall time spent on planning, design and construction phases.

There is another approach to test the problem of accuracy. By comparing maps produced by different methods of photo interpretation or by different people to a map considered to be a reliable standard, one can derive ratios of correctly interpreted acreage to total acreage. These ratios allow the comparison of percentages of correct interpretation as a function of the photo-interpretation methods, the scale, or some other attribute. This is the procedure followed by Pomerening and

Cline [206] and Thornburn and Liu [245].

Pomerening and Cline found that field checking resulted in consistent increases of accuracy for each method of photo interpretation, particularly in the complex areas. They also noticed that complexity of the area had a profound effect on accuracy for each of the five methods used. The results also showed that mapping on the basis of either parent-material, or stoniness or drainage was consistent as long as field checking was permitted; otherwise the percentage of correctly mapped areas would drop radically. Finally, it was found that the interpreter's knowledge and background were controlling factors.

Thornburn and Liu's results indicate that based on comparative mapping, as did Pomerening, the percentage of total area with corresponding map units is high if the basis is the parent material groups (77%) but low if the basis is the pedologic soil series (27%).

Such results indicate the validity of mapping soils on the basis of parent material and land form relationship with the assistance of sufficient field correlation. But such comparative studies also test the individual's ability to interpret photos, just as well as they test the mapping techniques.

Thus three things must be clearly distinguished: 1) the content of the photos, 2) the interpreter's ability to extract the content, in other words, to detect, identify and indicate the significance of what he sees, and 3) the actual ground truth, or what things are in reality.

It may well happen that the photo indicates similar gray tones and textures for different objects and thus does not report all the ground truth. On the other hand the interpreter may be able to extract only so

much of the photo content due to his limited capability. This is to show how relative it can be to speak of accuracy.

The last sections of this introductory chapter contained a review augmented by the author's comments of what engineering soils maps are, what they are meant for and how they are produced. Aerial photographic interpretation was indicated as a method of obtaining the information but relatively little was said about the technique. Following is a review of information on this matter and of other means of remotely obtaining soils information over an area.

CHAPTER 2

REVIEW OF AIRPHOTO INTERPRETATION AND MULTISPECTRAL REMOTE SENSING METHODS

To researchers in remote sensing and aerial photographic interpreters, the use of airphotos becomes more and more diversified as they see the birth of new sciences: space photography, space geology, environmental sciences and the grand scale attempts to solve some of mankind's great problems, problems created by the expanding population, problems of reclaiming land for agricultural development, for water supply and conservation, for expanding urban areas and many more.

Far from being a static field, aerial photography has been very active and has evolved considerably over the last thirty or forty years.

Remote sensing has evolved extremely fast as it started just a few years back. Remote sensing has been defined as the collection of informative data on objects, in a remote manner; the nature of the "data" is either electromagnetic, mass, field force or other energy manifestation, and "remote" refers to largely distant whereby the probing instrument does not touch the object being investigated.

This definition would permit inclusion of aerial photography under the broader scope of remote sensing and it is logical to do so. But for our needs, aerial photography will be treated separately because of its distinct origin and its evolution quite different than that of remote sensing. And remote sensing here will be restrained to the multispectral

imagery obtained over the different regions of the electromagnetic spectrum, ultraviolet, visible and infrared, while, in fact, it includes also radar imagery and passive microwaves.

The next two sections will review black and white and color photo interpretation. A third section will give a short summary on multispectral photography and a fourth section will discuss multispectral and infrared imagery.

2.1 Review of Black and White Aerial Photographic Interpretation Methods

This section is not meant to cover the principles of airphoto-interpretation in all the details. This is covered lengthly in the literature. Belcher [24], Colwell [48, 49, 52], Frost [82], Mollard [180], Miles [169, 171], Rib [211] and many more have documented the aspects of photo interpretation as related to engineering soils and earth materials. In the same manner, numerous scientists and engineers have written papers, reports and books on airphoto interpretation as applied to agriculture, forestry, geology, geography and numerous other aspects of man's activities [15, 233, 50].

The purpose here is to review what was done to better appreciate what the newer materials like color photography, multispectral photography and imagery have to offer. This chapter will also review the newer approaches in remote sensing as they may affect the civil engineer.

2.11 Basic Concepts

Interpretation of black and white aerial photographs in order to obtain engineering and scientific information started in the late 1920's. The soil scientist started using them in the field and civil engineers

began to use them for location studies. The Armed Forces became interested in aerial reconnaissance using photography during World War Two, particularly in organic terrain and mobility studies.

Belcher discussed the concept of land form as an important source of information for obtaining engineering characteristics of soils [18, 20, 22]. He emphasized that the land form is a key to the type of parent material and that the parent material is a key to the general physical properties of the soils. He pointed out the importance of climate, mode of origin of the land forms, drainage and relief as major factors influencing the formation of soils. He discussed the concept of photo patterns for soils [21, 23], indicated the engineering significance of land forms [24], and the importance of microforms and microfeatures [26]. Belcher and his collaborators prepared a report with information on the use of photo-interpretation to define engineering soil properties [27].

Frost studied the use of airphotos to locate granular materials and the factors limiting the use of airphotos [78, 80]. Parvis studied drainage patterns as a factor in photo-interpretation [202, 203]. Miles investigated the preparation of drainage maps and engineering soils maps for highways [165, 166, 167]. Altschaeffl [2] studied the moisture and other natural variables as they affect photo tones and McLerran [161] reviewed the significance of photo interpretation in highway programs.

From these early efforts, a group of basic concepts were derived. They have been extensively used in teaching airphoto interpretation [82]. They have been reviewed in a paper by Miles [169].

1) The Land Form-Parent Material Concept: it is based on the fact that under similar conditions of climate, topography, time, original formation and biologic agents, a given parent material will produce a soil with significantly the same engineering properties; and, in a given geological environment, land forms contain similar parent materials.
2) The Concept of Repetitive Units: similar geological processes and environmental conditions will always produce similar land forms.
3) The Concept of Photo Pattern and its Elements: the airphotos are made up of discrete units which constitute a pattern. The pattern can be broken down into elements of forms and tones and textures. The elements of form are due to the topography, drainage, erosion and deposition. The elements of tones and textures are due to the soils and rocks, the vegetation, the land use and water bodies (see Figure 3).

These concepts permit dissection of the airphotos into elements and, by the process of inference, association and deduction, extraction of information from the photo.

The reader will find additional information in the following references: Colwell [50], Lueder [149], Frost et al. [82], Miles et al. [170], Mollard [181], Bandat [15], Ray [209], Avery [12].

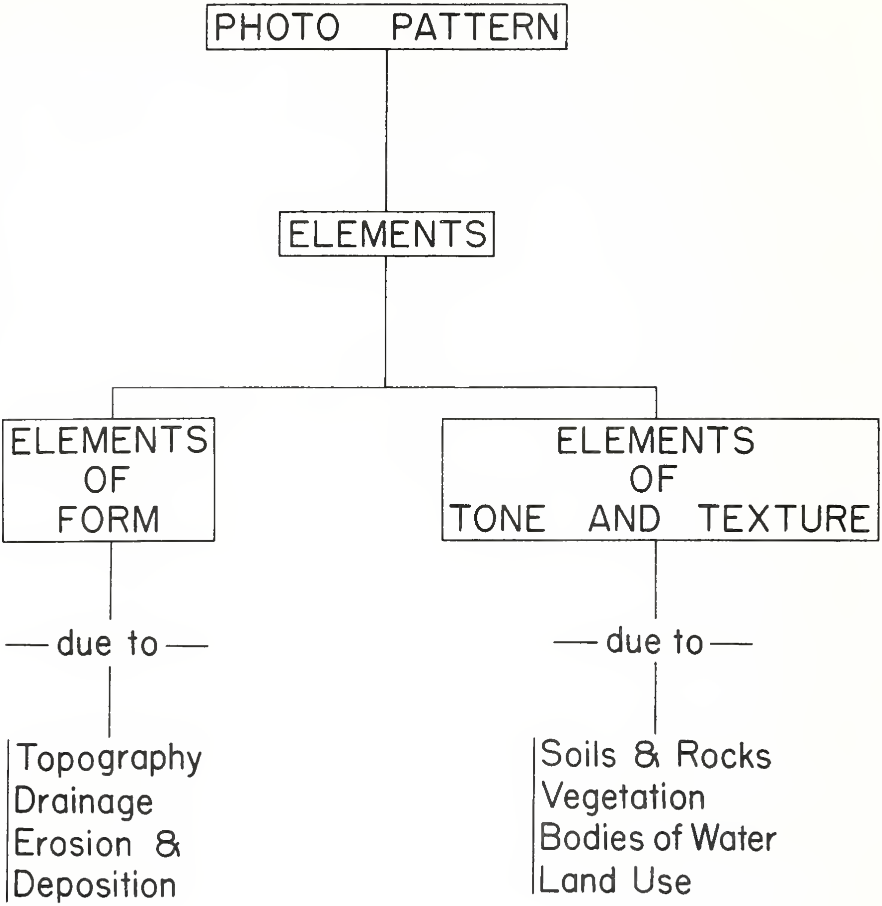

FIGURE 3. BASIC CONCEPT IN PHOTO-INTERPRETATION: THE PHOTO PATTERN AND ITS ELEMENTS

2.12 The General Procedure

From the many references used in the research, the most relevant information is summarized in Figure 4. It is an attempt to answer questions raised in the literature [65] as to what is the process of photo-interpretation and how is the photo interpreter's mind operating?

Figure 4 is divided in three parts. The upper part shows that a photo contains information which is subdivided into photo elements (grey tones, shapes, lines, textures, etc.). By the process of analysis, these are grouped to make patterns and by inference, the pattern is recognized as being either a lake, roads or a town, etc. This is a rather fast process for the simple case. The more intricate cases are analyzed step by step and additional information is gained by adding up the contribution of each specific photo element (indicated by dark triangular arrows) and constitute the processes of inference (right hand side of Figure 4). The trained photo-interpreter asks himself the appropriate questions in order to extract all the possible details from the photo elements. The better his training and experience, the faster and the more accurate his inference.

As a result of the inference processes, objects on the photo are identified and based on education, background and experience (middle part of Figure 4), the photo interpreter interprets the significance of objects identified.

The different steps of the inference process are most critical to the photo-interpreter's success. In practice, there are more questions raised than actually shown by the arrows. The point is that they are numerous and are raised one at a time, till the photo interpreter by successive progress finally identifies the object or the scene.

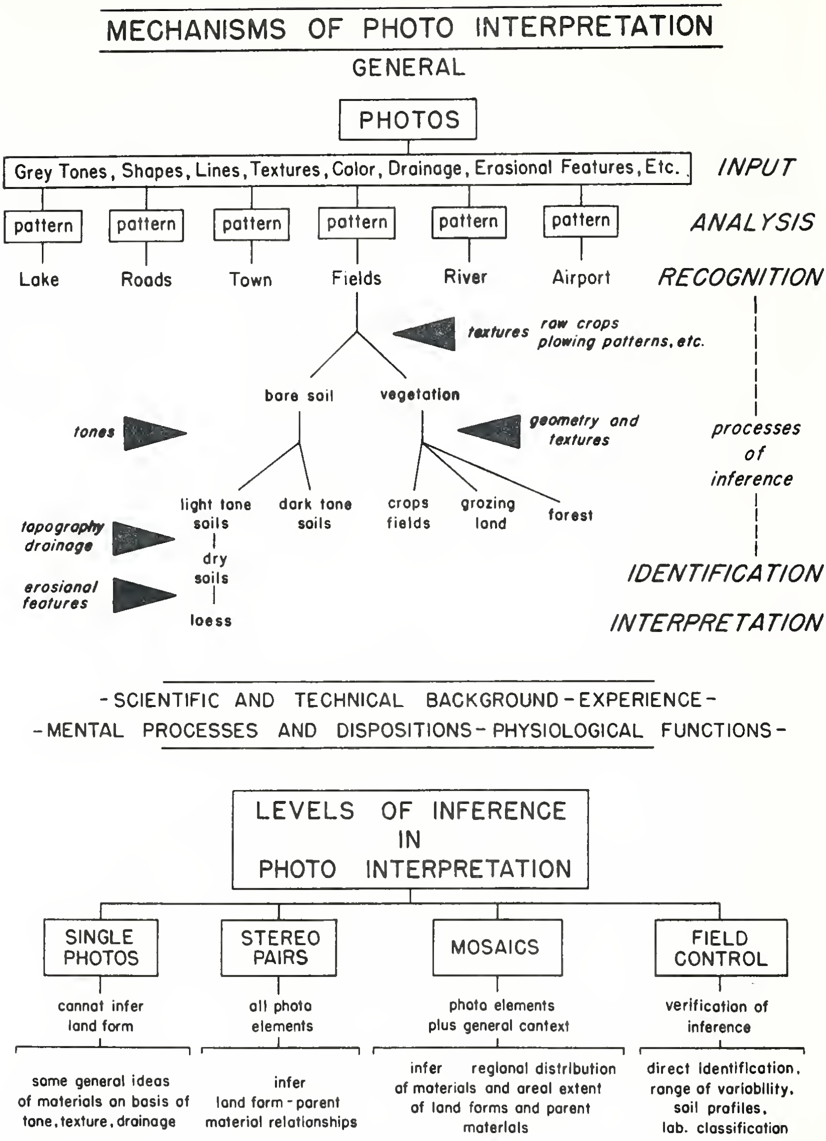

FIGURE 4. GENERAL PROCEDURE AND PHOTO-INTERPRETATION INFERENCE LEVELS IN ENGINEERING SOILS MAPPING

The distinction must be made between recognition of an object and its identification. One can detect its form, tone, etc., but may be unable to identify or attach a name. If one has sufficient positive answers at each step of the inference process, sufficient information is accumulated to produce "convergence of the evidence" and thus identify the object.

Distinction is also made between identification and interpretation. Identification relates to naming of an object and interpretation relates to judgement that attaches a significance to the object identification.

Identification and interpretation are based on the scientific and technical background of the photo-interpreter, his experience, and his mental disposition (see middle part of Figure 4). It also is a function of the acuity of the physiological function of his eyes; stereo perception, eyesight resolution, and overall physical condition [95].

The third part of Figure 4 shows the different levels of inference in aerial photographic interpretation. It shows that for each level, an increment of information is gained. From left to right, from single photos to stereo pairs, the increment is the third dimensional information. It is part of the photo element of form, and is necessary to identify land forms which in turn are most useful to infer the soil groups present on the land form.

An increase in information is achieved by going from stereo pairs to mosaics. The gain is in additional information on the overall geomorphological processes that took place in the area and on the regional distribution of materials. This step is of absolute necessity in site selection problems, for instance.

The fourth step is to use field control. This is to verify the inference and to establish a direct identification of the earth materials, range of variability, to prepare soil profiles and to test samples for classification purposes. With this information, it is possible to go by similitude, association and deduction and make a positive interpretation. This is an important step which has been emphasized in Chapter 2.

The first two levels of inference in the overall procedure or mechanism of photo-interpretation are emphasized on Figure 5 and Figure 6. Figure 5 indicates that only a final identification such as dry bare soil or stubble ground, is reached. This is of relatively little help to interpret the materials. The second level of inference (Figure 6) indicates that the dry bare soil can be divided into beach ridge and sand dune, on the basis of land form as indicated by the third dimension. This immediately is of interest for the inference of the properties of soils. The mosaic will show the extent and distribution of these land forms and their related materials.

The last step will be to go in the field and sample each land form and determine, for instance, that the beach ridge has coarser sand and the dune finer and more uniformly graded sand. This completes the interpretation cycle. Then all areas "looking like" the areas already sampled will be labeled with the same engineering soil group symbols.

2.2 Review of Color Airphoto Interpretation Methods

The problems of using color aerial photography range from high cost to the narrow exposure latitude and the more rigourous controls required during processing. Color film shows objects in their natural colors, and this is a major attribute. There is no doubt that if color is so

MECHANISMS OF PHOTO INTERPRETATION

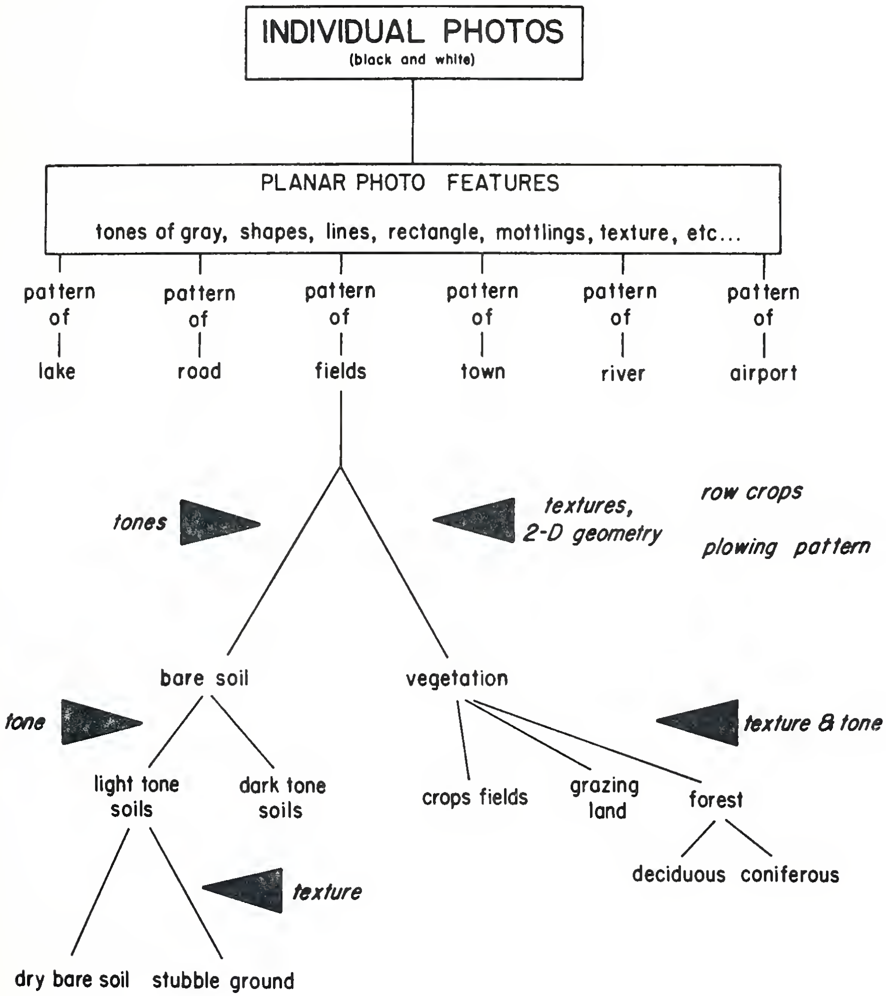

FIGURE 5. FIRST LEVEL OF INFERENCE AND THE GENERAL PROCEDURE OF PHOTO-INTERPRETATION

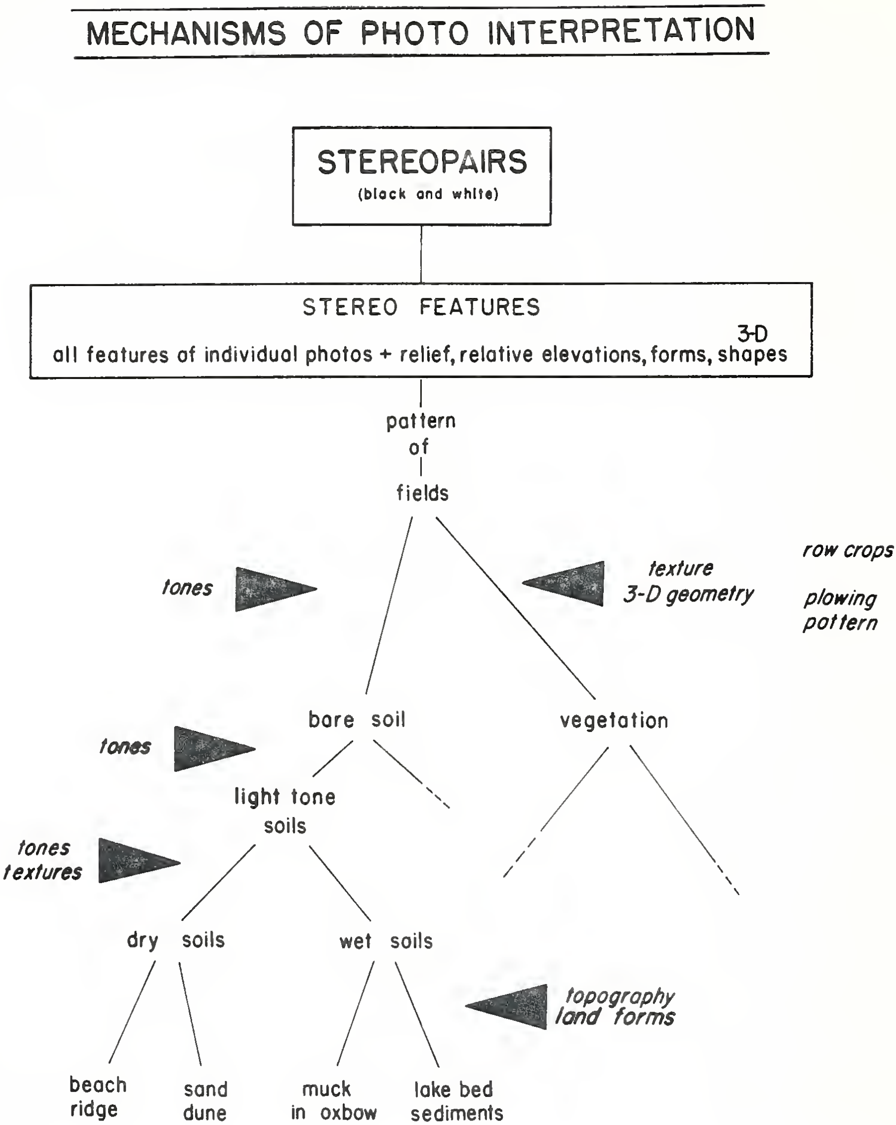

FIGURE 6. SECOND LEVEL OF INFERENCE AND THE GENERAL PROCEDURE OF PHOTO-INTERPRETATION

extensively used today, it is due in greater part to its property of rendering natural colors and this increases its interpretability [238].

Many reports on experimental work with color aerial photography and its applications are reported in the literature. All these efforts were recently summarized in the "Manual of Color Aerial Photography" [227]. The first part of the book gives the fundamentals of color, the planning of color photographic missions, camera optics, film sensitometry, and the information on processing and printing. The second part is related to the applications of color photography.

2.21 Studies with Color Photography

This section is a brief review of some of the research and applications of color aerial photography. Rib [211] reviewed the great majority of the references previous to December 1966. The following notes continue his work in an attempt to link all these sources of information together.

The fundamental question of the sensitometry of color films was treated recently by Current [58], Fritz [77], Sorem [228] and also in great detail by Cretcher and Balentine Reed [in 227]. It is a subject most important to help understand how colors are rendered by the three layers of the film (two in the case of the SN-4 Russian false color film).

For a better understanding of the role of color it must be said that the color on the photo is not necessary exactly identical to the color of the photographed object. Sorem [228] stated:

> "As we are concerned here with a picture as a source of information rather than for its emotional or artistic qualities, we assume that the more accurately it (the color

> photo) conveys the same sense impressions as the original, the better. But these impressions are evoked by pictorial clues which are not like the original in any exactly measurable sense. This is an obvious, yet subtle, point. Failure to understand it has been responsible for overly optimistic hopes for automated photo-interpretation. Failure to understand it also leads some photographers to expect to be able to measure such things as the per cent reflectance, or the spectral reflectance characteristics of objects in photographs of them."

The Kodak color infrared film responds in a different manner. When developed to a positive, this film shows the color of objects in the same sequence as they would appear on regular color film, but this sequence is shifted one block towards longer wavelengths [77].

Knowing the spectral reflectance of an object (i.e., the percentage of energy reflected back from the surface of an object as a function of the wavelength), one can predict its change of color on the film. For instance, healthy vegetation normally reflects very strongly in the near infrared (also called reflective infrared) and this is translated into magenta or red on the photographic film. On the other hand, unhealthy vegetation will have weaker reflectance in the near infrared, stronger reflectance in the blue-green than healthy vegetation and the film will show less red and more cyan (blue). Knowledge of the sensitometry of the film and the reflectance properties of the objects or phenomena to be observed, like plant disease, water pollution etc., is at the base of effective color photo-detection.

Figure 7 is a summary of the aerial films used in the present research project along Highway 37 in Indiana. This figure shows the principal film types, their response bandwidth and the filters used.

Most striking among the film types listed on this figure is a new system developed by Kodak and called "Kodak Aero-Neg Color System" [227].

AERIAL PHOTOGRAPHS
(VISIBLE AND INFRARED RANGES)

	BLACK and WHITE	BLACK and WHITE INFRARED	COLOR	COLOR INFRARED
RESPONSE	TONES of GREY	TONES of GREY	HUES CHROMAS VALUES	HUES CHROMAS VALUES
INTERPRETATION MEANS	PHOTOPATTERNS DUE TO form tones texture	PHOTOPATTERNS DUE TO form tones texture	PHOTOPATTERNS DUE TO form color texture	PHOTOPATTERNS DUE TO form color reversal texture
SOME EXAMPLES of FILM TYPES	PLUS-X PANCHROMATIC	INFRARED AEROGRAPHIC TYPE 5424	EKTACHROME TYPE 8442 or EKTACHROME MS TYPE 2448	EKTACHROME INFRARED TYPE 8443
WAVELENGTH RANGE	.4 TO .7 MICRONS	.7 TO .9 MICRONS	.4 TO .7 MICRONS (3 layers)	.5 TO .9 MICRONS (3 layers)
FILTRATION USED	MINUS BLUE WRATTEN NO. 12	MINUS BLUE and GREEN WRATTEN NO. 25A MINUS B.G.R. WRATTEN NO. 89B	HAZE FILTER (HF-3) ANTIVIGNETTING FILTER	WRATTEN NO. 12 EMULSION FILTER (EF SERIES) COLOR COMPENSATING FILTER (CC SERIES)

FIGURE 7. SUMMARY ON AERIAL PHOTOGRAPHIC FILMS. THE FILM TYPES GIVEN AS EXAMPLES WERE USED FOR THIS RESEARCH.

The film of this system is the Kodak Ektachrome MS Aerographic film, type 2448 (Estar Base) (replaces type SO151). This film can be processed either to a direct viewing transparency or to a negative for printing. When processed with the modified Kodak Color Process C-22 to a negative, it can be used to obtain any of the following: 1) color diapositive plates, 2) color paper prints, 3) color film transparencies, 4) black and white diapositive plates and 5) black and white paper prints. This great versatility can be extremely useful in airphoto interpretation and in surveying and mapping by combining both the advantages of color and the lower price of black and white. There are other advantages too, like the greater exposure latitude of this film when processed to a negative.

Factors influencing color aerial photography are numerous. They include (1) the ground conditions, (2) the atmospheric conditions, (3) the film / filter combinations, (4) processing, printing and viewing. These factors were reviewed in greater detail by Rib [211], Colwell [52], and in the "Manual of Color Aerial Photography [227].

2.211 Experiments on Color Interpretability of the Scene. These experiments were mostly conducted by the American Society of Photogrammetry in collaboration with the U. S. Army Engineer Topographic Laboratories, the U. S. Air Force, the U. S. Coast and Geodetic Survey and the U. S. Geological Survey. These tests were designed to study specific problems created by the use of color aerial photos and equipment, like the fall off of color saturation at the edge of camera field. They were also designed to make a comparative study of aerial films in terms of interpretability, target detection and discrimination.

A summary of these investigations was presented by Anson [4, 5, 7, 8]

and by Anson and Quick [in 227]. The Bennettsville, S. C. test area was used to study the increase in information for each film type, the interpretability (rapidity) and the fidelity of the interpretation. The Davis Campus test was designed to study the fall off of color at camera field edges. The Yosemite experiment (by Anson and Colwell) [55] was designed to study specific discrimination for several types of soils and rocks. The Phoenix, Arizona test site was used to study the scale-altitude effect on detectability, the best film type for specific interpretative uses, the problem of sun angle, and the type of ground truth to be collected in future research.

Mintzer [176] presented the results of five different comparative studies of the Phoenix, Arizona test range. From these experiments, it was concluded that color infrared film is superior for mapping drainage, vegetation and moist soils, and natural color film is superior for mapping cultural features and soils. Similar conclusions were also reached by Anson [4, 5, 8].

For the interpretation of terrain and soils, it was also concluded that the best scale was 1:20,000, and the best film was natural color. At a scale of 1:40,000, the best films were natural color for cultural features and color infrared for natural features, but at a 1:60,000 scale, color infrared becomes the best film for the overall scene interpretation [176]. It was also concluded that the degree to which color and color IR aided the interpreter was a function of the scale and the specific features examined.

<u>2.212 Experiments Applied to Highway Engineering</u>. The two applications of most direct interest for the present report are 1) surveys for

materials and 2) engineering soils mapping.

The problem of materials surveys using color photography was investigated by Chaves, Shuster and Warren [42] and further tested by Chaves and Shuster [43, 44, 45]. The usefulness of color in an environment of rugged terrain and diversified soils and rock types was evidenced by their research conducted in Colorado-Utah area (district 9 of Bureau of Public Roads).

It was concluded from their investigations that natural color film helped differentiate soils, shale as against sandstone, sands and gravels that contained high percentages of lava fragments and it helped delineate terrace remnants and organic soils much more accurately. It also accelerated the work. Color infrared film was found to be more useful than natural color film to differentiate limestone, natural and cultural objects, water seepage, boggy ground and hydrologic features.

Another set of investigations were conducted by Mintzer on soils mapping, drainage mapping and landslide susceptible terrains. These case histories showed that natural color, because of the contrasting natural color tones, helped in the interpretation of gully shapes, of gradient and of erosional features. Infrared color film helped more than natural color in the case of intermittent streams and drainage mapping and to collect information on land form and vegetation [176].

Rib [211] conducted a comprehensive study on the comparative performance of color films (first phase of the present project). The conclusions were reported earlier. It is important to recall that natural color film was found as the best single source of information for mapping soils as it is based on their natural color appearance, but color infrared

was considered more effective to map wet areas, wet and boggy soils and drainage features.

These results in addition to other applications of color films are summarized in Table 3. It appears from this resume that both color and color infrared films are useful for engineering applications. There appears to be a preference for color in soils mapping and for color infrared in the case of general purposes mapping.

2.213 Quantitative Approach to Color Photo-Interpretation. Chaves et al. [42] suggested that attempts be made to determine, by means of densitometer and microdensitometer measurements, if a quantitative approach to photo-interpretation of color films could be a reasonable way to attack the problem of automatic interpretation.

Part of the problem was to design a quantitative method of coding colors. This was investigated during Rib's study on a multispectral approach to mapping soils, [87, 212, 227]. This system has been used by the author and results appear in a later section.

2.22 Color in the General Procedure of Photo Interpretation

It is documented that color and color infrared films, because of the new dimension they confer to aerial surveillance, are an asset to photo-interpretation techniques. The new dimension of color conferred to the element of tone in the general scheme of photo-interpretation is most useful. Figure 8 shows the different levels at which color helps complete the processes of inference (refer also to Figure 4 on page 32). It is seen that this new pattern element allows for a more accurate and more rapid answer.

TABLE 3.

COMPARATIVE STUDY OF COLOR FILM ADVANTAGES IN ENGINEERING APPLICATIONS, BASED ON PREVIOUS WORK

Reference	Type of Research	Advantages	Conclusion on most useful film			
			BW	BWIR	C	IRCD
Bay (in Smith) 1968	Hydrologic studies	Water quality; opacity, transparency and color, flow patterns and currents, concentration of effluents.			*	
Chaves et al. 1962	Materials surveys	Cultural features, soil types, seepage zones and minor drainage ways.	-		*	
Chaves et al. 1964	Materials surveys	Differentiate sand and gravels with large amount of lava fragments, differentiate shale vs sandstone, delineate terrace remnants, organic soils mapping.	-		*	
Chaves et al. 1968	Materials surveys	Differentiate soils and shale.	-		*	-
		Differentiate limestone.	-		-	*
		Natural features and cultural objects.	-		-	*
		Greater haze penetration.	-		-	*
		Differentiation of water seepage	-		-	*
		Boggy ground and hydrologic features.	-		-	*
Mintzer (in Smith, 1968)	Soils mapping	Contrasting natural color tones.	-		*	-
	Drainage mapping	Runoff lines density.	-		-	*
	Landslide susceptible terrain investigation	Data on landform, drainage system and vegetation.	-		-	*
		Data on gully shape and gradient, erosional features, natural color tones of soils.	-		*	-
Mollard (in Smith, 1968)	Landform analysis				*	

NOTE: BW: Black and White film and prints. BWIR: Black and White Infrared film and prints. C: Color film positive transparency and color prints from color negative. IRCD: Infrared color film (Camouflage Detection).

* indicates the most useful film.

\- indicates other films tested in the investigation.

TABLE 3. cont'd.

COMPARATIVE STUDY OF COLOR FILM ADVANTAGES IN ENGINEERING APPLICATIONS, BASED ON PREVIOUS WORK

Reference	Type of Research	Advantages	Conclusion on most useful film			
			BW	BWIR	C	IRCD
Pressman (in Smith, 1968)	Geologic mapping	Greater number of surface materials identified by their colors.			*	*
		For high altitude work.				*
Pryor (in Smith, 1968)	Highway engineering				*	
Rib, 1967	Soils mapping	Natural color appearance of soils; due to shades of colors possibility to differentiate if tones are due to soil color, moisture, vegetation or cultural features.	-	-	*	-
Stallard, et. al. 1965	Highway engineering	Soils surveys.	-		*	
Strandberg (in Smith, 1968)	Water pollution analysis				*	*
Swanson (in Smith, 1968)	Shoreline mapping	Bottom features as deep as 20 feet; tidal currents in bays; harbors and open sea as deep as 25 feet; more accurate triangulation, measurement of land subsidence or uplift.			*	
Welch, 1966	Materials studies	Glaciated terrain: soils and rocks.			*	
		Vegetation types and general interpretation.				*
Whitten (in Smith, 1968)	Earthquake damaged area	Fault scarp under water.	-	-	*	-

MECHANISMS OF PHOTO INTERPRETATION

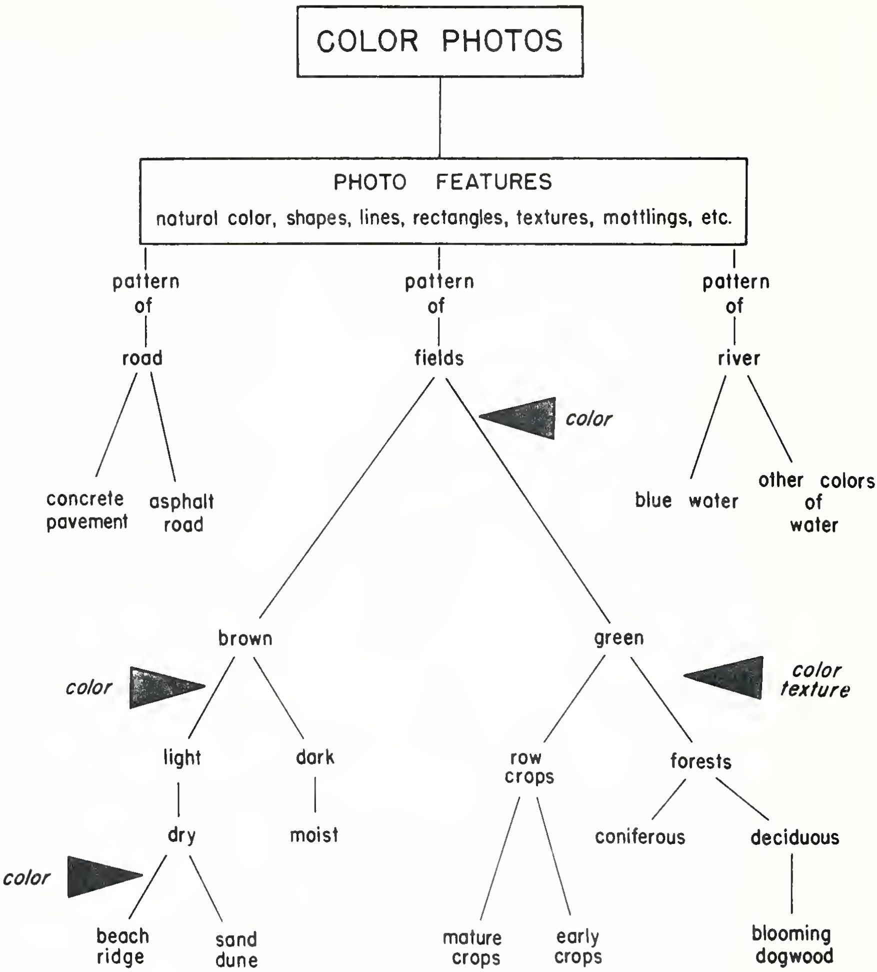

FIGURE 8. COLOR AS AN ASSET TO THE GENERAL PROCEDURE OF PHOTO-INTERPRETATION

Taking the example that was used above, fields can be separated on the basis of color into brown fields and green fields (Figure 8). The brown fields correspond to stubble fields or bare soils. This is not as evident on a black and white photo, and the interpreter must search a little longer. This is how color can save time and procure a more accurate answer. Color adds to the ability to determine regional extent of similar materials.

Color has limitations. Besides a higher cost which may not always be offset by the gain in information, there is a shorter exposure latitude than for black and white, and the films and prints do not have the stability needed if airphotos are to be used as a permanent record. At high altitude there is a significant color change (see Pressman, in [227]) except for haze-free days which are rare; although color infrared may offset this problem. Finally photo-interpreters trained on black and white generally take some time to fully take advantage of the color element.

Referring to the problem of automatic-interpretation and the scanning devices used in recent approaches, it must be pointed out that in the process of photo-interpretation, the human eye does not actually scan the photo; it collects information on a given area that may be several square inches in extent. In other words, it actually "sees" a piece of the photo. This is an important point to consider in the design of automatic-interpretation devices; maybe that a device reading the photo on a matrix format rather than scan lines would accelerate the collection and facilitate the sorting of the data.

2.3 The Multispectral Photographic Method

Multispectral or multiband photography, as opposed to multiband imagery, is obtained by standard photographic cameras except that, through an appropriate use of films and filters, the scene's electromagnetic energy is divided into a given number of narrow spectrum bandwidths. The multispectral imagery is obtained by non-conventional means and will be described later.

2.31 Definitions, Principle, Instrumentation and Purpose

One could conceive of multispectral photography as one of a broader group of techniques that are referred to as "image enhancement techniques." All have the basic purpose: "---to make the target of interest easier to identify and interpret" [211, p. 82]. Those operating by conventional photographic methods are the following:

1) film-filter combinations to investigate a narrow region of the spectrum by standard filter-in-front-of-film technique at the time of exposure.

2) enhancement by special laboratory processing which permits an increase in the contrast between target and background (Rib 1967).

3) multispectral photography which consists of taking a photo of the scene with a multilens camera (from generally three up to nine lenses) or a bank of several identical cameras equipped with an appropriate set of filters.

The filters allow only the energy (light) in the discrete bands to be photographed. A black and white negative picture is thus obtained in each band. These negatives are in turn used to make positives which are corrected for both the exposure and the gamma (see Yost and Wenderoth in Smith [227]). Appropriate color filters used in projection permit reconstitution of the color image (additive colors concept) and color enhancement can take place by simply changing the intensity of the brightness and the saturation lights and/or the filters (hues).

The principle of multiband photography is based on the different reflectance properties of materials. Fritz [77] stated:

> "Ideally to detect photographically the differences or changes in spectral reflectance, it would be desirable to have spectrophotometric curves from which to find spectral regions of greatest difference. With suitable filters, photo could be made in these regions and the regions where no difference occurs could be eliminated".

As fundamental as spectral reflectance curves may be to this subject, it is only in recent times that interest has led to developing such curves [61, 74, 209, 195]. Spectral reflectance curves uniquely define the color of an object, but the color itself does not tell anything about the spectral reflectance of the object ([227], see Yost and Wenderoth).

The instrumentation for taking such photography varies. In fact it can be as simple as a set of 3 or 4 cameras (35mm) with appropriate filters [156, 198]; or it can be quite sophisticated like a set of Wild RC-8 and Fairchild WC-4 cameras in the NASA aircraft; or the 4-lens camera developed by Fairchild Camera and Instrument Corp. ([227], see Appendix by Orr and Appendix by Yost and Wenderoth) [13, 263]; or the 9-lens camera developed by Itek Corporation and the University of

Michigan [179]; or the multiband continuous strip camera [259].

The purpose of the multiband photo approach is to enhance the different spectral reflectance characteristics of the materials or of the components of the scene, and hopefully simplify the interpretation while increasing at the same time its accuracy.

2.32 Applications of Multispectral Photography

The majority of the tentative applications have been related either to geology or to forestry. Fischer [74] studied the spectral reflectance of some rocks and minerals to obtain better film-filter combinations in view of differentiating rock units by photographic means. Other attempts were also made on geology applications by Poley [205], Cronin [56], Walter [251], Brown et al. [36]. Colwell and his collaborators have extensively used this technique [51, 53].

In all of these attempts, it appears that there is no straightforward approach. It seems as though each attempt was an entirely new research program. The reason for this is that in each case, the desired spectral reflectance curves needed to define the appropriate bands are not known. This strongly emphasizes the need for further spectral reflectance studies and the need for further development of interference spectrometers to investigate reflectance properties over a broad portion of the spectrum (UV to far IR), in the field.

One can see limitations that users will probably have to live with for quite some time to come. It is an approach that can treat a problem on a rather limited area, generally covered by one or a few sets of photos; in other words it does not lend itself very easily to problems involving very large areas as it would be expected from a remote sensing

method. Another limitation is created by the fact that it has little to offer in terms of automatic interpretation due, in good part, to the projection set-up, the discontinuity of the separate frames and the laboratory processing requiring excellent control.

2.4 Multispectral and Infrared Imagery

Multispectral remote sensing is a technique by which sensing is done simultaneously in several bands of the electromagnetic spectrum from the ultraviolet to the infrared and microwave range. The multispectral imagery itself, once processed, is a set of film strips showing areas of different gray tones related to the various energy intensities that are recorded for each band. Or it can be a set of magnetic tapes on which is recorded the energy as collected by the detectors.

Sensors have been divided in two classes; active and passive. The active systems send a signal and collect the returned energy from the scene. The passive systems collect the "natural" energy irradiated (emitted and/or reflected) by the materials being "sensed".

Dr. R. Hoffer has defined remote multispectral sensing in the following manner [98]

> "Multispectral remote sensing as used here is the detection and recording, from a distant or remote location, of reflected or emitted electromagnetic radiation in many discrete relatively narrow spectral bands between 0.3 micron to 14 microns wavelength, and also in radar bands from 0.86 to 3.0 cm."

This definition applies in this report with the exception of the radar imagery which was not available for this project.

The basis of multispectral remote sensing is that plants and materials at the surface of the earth (or any planet for that matter) possess the fundamental property of reflecting or emitting electromagnetic

energy differentially over the spectrum. In the visible range this property is translated by the color.

This property seems to be typical of each material and is due to the more fundamental properties of energy absorption and surface reflectance, all of which depend on the chemical composition, crystalline structure, surface texture, moisture, specific surface and surface roughness. For the present purpose the spectral properties will be divided in two sections: the spectral properties in the visible range and near infrared and the emissivity in the middle and far infrared (see Figure 9). In this manner it is valid to speak of reflectance in the visible and near infrared (0.4 to 1.0 micron) and of emissivity for the range 3.5 to 14.0 microns.

In the visible and near infrared (also called reflectance infrared), early work on reflectance properties of materials by Krinov showed great promise for the classification of materials [119]. Further research on this subject, all very fundamental to both multispectral photography and imagery, were conducted by Ray and Fischer [209], Romanova [215], Lyon [151, 152, 153], Lyon et al. [154], Olson et al. [195] and a few others.

Ray and Fischer measured the reflectance of some rocks (two different sandstones, one limestone and one red shaly siltstone) with a Spectronic 20 colorimeter with color analyser reflectance attachment, to define reflectance differences and to provide a better selection of filter in multispectral photography [209].

Romanova [215] also reports measurements of spectral luminance (reflectance) of different sands and rocks and their indicatrices of diffusion (or diffuse reflection). The results indicate a change in

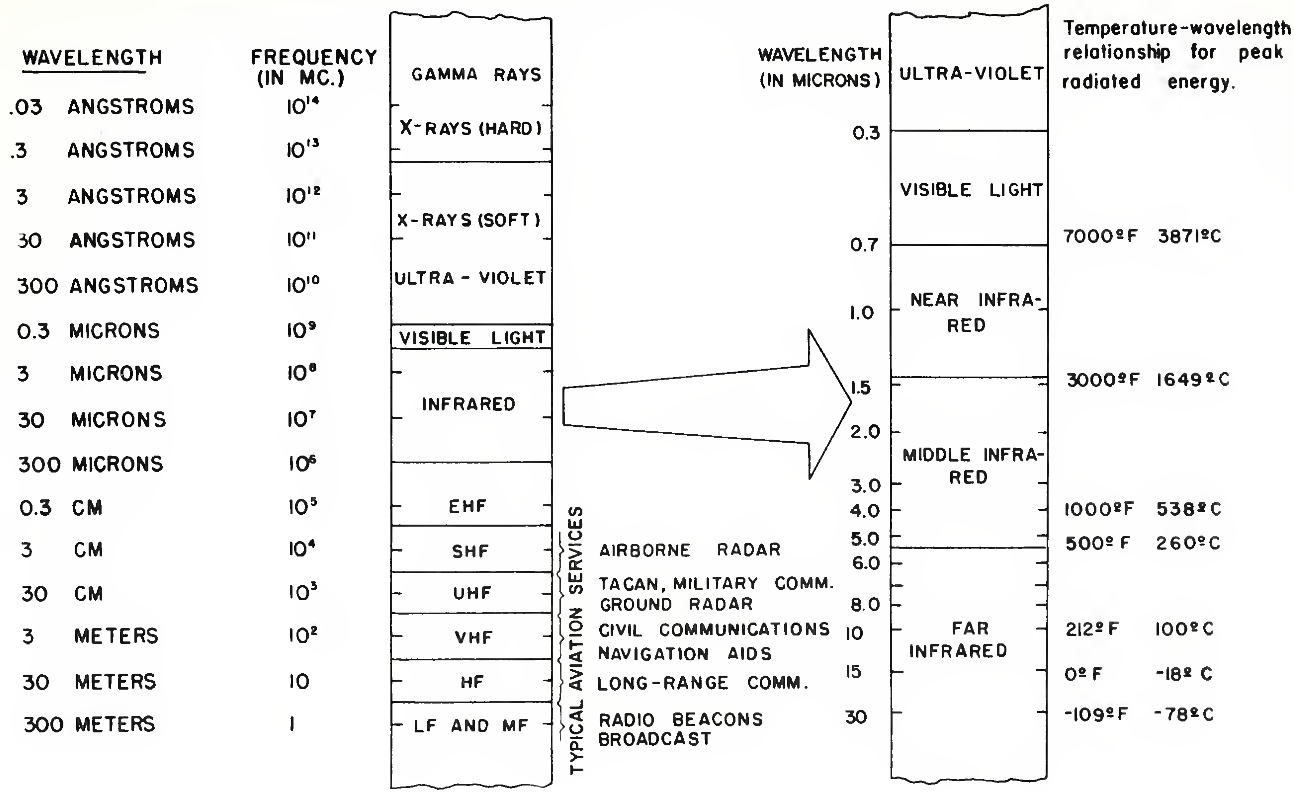

FIGURE 9. THE ELECTROMAGNETIC SPECTRUM AND DIVISIONS.

reflectance as the overall mineral composition changes. From Romanova's results it also appears that diffused reflection predominates over specular or direct reflection, thus explaining the importance of surface texture effects [215, p. 14].

Rib notes that relatively little has been done on soils in terms of reflectance but the basic different reflectance properties for the different classes of materials is sufficiently evidenced [211].

Other researchers worked on the problem of reflectance properties: Olson et al. [195], Schimpf and Aschenbremmer and also Keegan et al. [in 211], and Lyon and Burns [154].

There appears to be some problems on these measurements. They are very difficult to compare because the researchers did not use the same instrumentation, not to mention the problems of field measurements versus laboratory measurements, the latter not reproducing all the field conditions; namely the texture phenomena at the surface of the ground. All this implies that more research is needed on reflectance studies, most particularly for soils and rock materials.

Hoffer has reviewed some of the fundamental questions on reflectance properties. His approach is related to plants but the same questions would apply to soils and rocks. He asked: (1) are there characteristic differences in reflectance between the various species and if so at what wavelengths, (2) how much variation in spectral reflectance exists among individual leaves sampled within a field and (3) how much variation within a sample? [98]. In answer to this, numerous reflectance measurements have been conducted by the Laboratory for Agricultural Remote Sensing (LARS) personnel and it has been shown that there is

little variation within a leaf and between leaves of the same plant. There is a significant change between species and more so for dry leaves as compared to green leaves.

In order to answer the question of the differences possibly occurring on reflectance between field conditions and laboratory simulated conditions, instrumentation is being developed at LARS to obtain the spectral signature, in the field, of earth materials and plants, over a wide range, from the ultraviolet to the far infrared. Already such instrumentation is available for the infrared range [127] and in the very near future, further instrument modifications will permit to cover the entire range desired [see also 153].

The purpose or objectives of remote multispectral sensing are very diversified. It is expected that in the near future it will help solve some of the data collecting problems over large areas in such fields as the environmental sciences; the earth sciences; for the development of natural resources and for various types of surveys involving coverage of large areas. Colwell [55] expects such techniques to be used by the geologists, soil scientist, forester, agronomist, wild life conservationist, the hydrologist, oceanographer, sanitary engineer and the civil engineer. Many other scientists and researchers share this opinion to various extents. At the present, the problems are more to present the multispectral imagery in a useful form [105] and to apply the multispectral imagery to the engineer's and the scientist's needs.

Leighty et al. [139] summarized the capabilities of this approach in general terms.

Becker and Lancaster discussed the potential use of remote sensing in engineering. They indicated more specifically the possible uses of

infrared imagery. Their philosophy is that it would be a very helpful complement to airphotographs and other means of collecting engineering soils data. Infrared imagery would be most useful, it seems, in relation to problems of seepage, drainage and the like [17].

Rib described a number of potential uses of remote sensing to the field of highway engineering. He estimates that possible uses range from the early planning phases of route selection, traffic surveys, highway location surveys, land use, geology and soils surveys, drainage studies, construction materials location and plans for boring programs. The problem is to determine what sensor should be used under a set of given conditions and exactly how should the information be extracted from the remote sensing data (either photography or imagery or both) and how this should be presented and displayed in a practical and economical manner.

2.41 Elements of Infrared Physics: A Short Review

Figure 10 indicates the available remote sensing methods for civil engineering purposes. The aerial photography in the visible and the infrared and the multispectral photography have been the subject of previous sections. The radar imagery has been ruled out for this type of project. The multispectral imagery in both the visible and the infrared, covering the region from 0.3 to 14.0 microns is of concern in this section, and more precisely the 8-14 micron infrared band.

Radiation and temperature are closely related and matter above the temperature of absolute zero ($-273^{\circ}C$) will radiate some energy due to its molecules moving at different rates. The motion of molecules increases in amplitude and frequency as the temperature increases. If the distribution of numbers of moving molecules at different

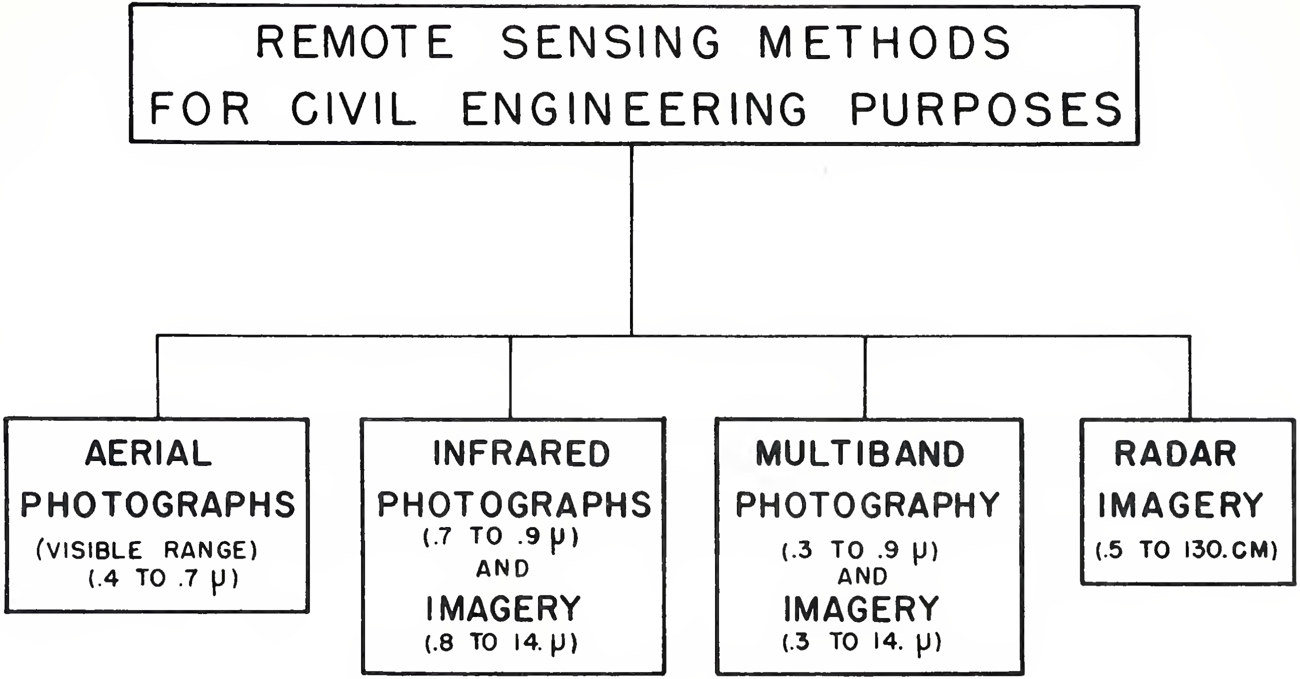
REMOTE SENSING METHODS
FOR CIVIL ENGINEERING PURPOSES
AERIAL
PHOTOGRAPHS
(VISIBLE RANGE)
(.4 TO .7 μ)
INFRARED
PHOTOGRAPHS
(.7 TO .9 μ)
AND
IMAGERY
(.8 TO 14. μ)
MULTIBAND
PHOTOGRAPHY
(.3 TO .9 μ)
AND
IMAGERY
(.3 TO 14. μ)
RADAR
IMAGERY
(.5 TO 130. CM)

FIGURE 10.

temperature is plotted on a graph, this distribution looks like a set of skewed bell-shaped curves as shown on Figure 11. These curves show that molecules in a given body are not excited at the same degree, but most of them have approximately the same degree of thermal agitation indicated by the plots of the bell-shaped curves. It also shows that this is true at any temperature, but more so at higher temperatures. On this figure, the degree of agitation increases from right to left.

Moving molecules are for all practical purposes, like oscillating electrical charges which will radiate electromagnetic energy. Its distribution will correspond to the molecular agitation distribution and consequently the electromagnetic energy radiated will be distributed over a wide range of wavelengths. Similar to the molecular agitation, the radiated energy also increases with an increase of temperature, and its peak is also shifted to the left, towards shorter wavelengths.

Radiation laws describe these phenomena. Lambert's law of cosine states that the radiant energy from an ideal diffuse radiator is proportional to the cosine of the angle from the normal to its surface. If J, in watts/steradian is the radiant intensity in a given direction (also called the radiant flux per unit solid angle, $dP/d\Omega$), the radiance N or radiant intensity emitted per unit area by a source is given by [115, 121]

$$N = J/(dA \cos \theta) \tag{2.1}$$

where dA is the incremental area, θ is the angle between the direction of sight and the normal.

The radiance is a measure of the brightness of the source and is defined in terms of unit area. For a point source or for a large sight distance, a correction has to be made and thus the radiance is the intensity per unit of projected area, and

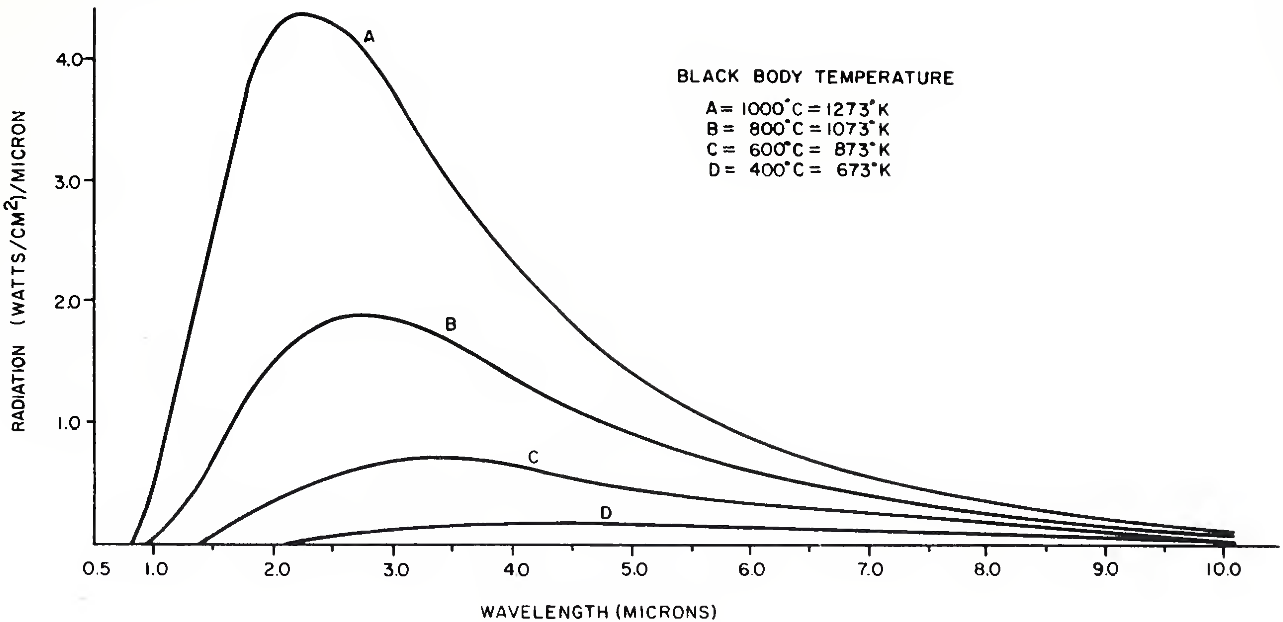

FIGURE II. BLACKBODY RADIATION CURVES

$$N = \frac{J}{dA\cos\theta} = \frac{dP}{dA\ d\Omega\ \cos\theta} \tag{2.2}$$

where the units for N are in watts/cm^2-steradian. For a perfect diffusor, the radiance is the same in all directions (definition of a Lambert surface) and N is a constant for any value of θ. In this manner, the radiant intensity J in any direction is given by

$$J = NdA\cos\theta \tag{2.3}$$

Knowing that the radiant emittance W equals π N, and applying the inverse square law, the equation for the radiant intensity of a given surface will be equal to

$$J = \frac{WA\cos\theta}{\pi d^2} \tag{2.4}$$

This is the intensity that will be received by a detector at a distance d from the surface A, which indicates that this intensity decreases as a function of the distance squared; for instance, an aerial scanner in an aircraft, will receive four times less energy if the altitude is doubled.

Kirchoff studied absorbed and emitted radiation and compared blackened and silvered surfaces. In 1859, he concluded that high absorptive objects are also good radiators. For imperfect absorbers and radiators, the ratio of energy absorbed by an object to the energy absorbed by a perfect absorber, at the same temperature, is the same as the ratio of emitted energy for these bodies.

This led to the concept of a blackbody: an object that absorbs all incident radiation and emits all the energy absorbed. There is no perfect "blackbody" in nature.

A description of the radiation from natural objects must include a factor which indicates how good a blackbody each object is. This factor is called "emissivity" and is defined as the ratio of the radiation emitted by an object to that emitted by a blackbody at the same temperature.

The Stefan-Boltzmann law takes its name from the two men who independantly studied emitted radiation phenomena. Stefan (1879), after empirical studies, and Boltzmann (1884), after theoretical analysis, concluded that radiation emitted from an object is equal to the product of its area times the fourth power of its absolute temperature, times its emissivity and times a constant of proportionality. This equation is

$$W = \epsilon \sigma T^4 \tag{2.5}$$

where W = radiant flux emitted per unit area

ϵ = emissivity (unity for a blackbody)

σ = Stefan-Boltzmann constant = 5.673×10^{-2} watts $cm^{-2} {}^{o}K^{-4}$

T = absolute temperature of the source in ^{o} Kelvin

Wien's displacement law resulted from investigations on blackbodies. Formulated in 1898, this law states that the product of the peak radiation wavelength (see Figure 11), and the absolute temperature is a constant. This is very significant and indicates that the radiation peak is displaced to shorter wavelengths as the temperature increases. On Figure 11, a graphical representation of Wien's law would be given by joining the maximum temperature points for each curve. The mathematical expression of Wien's law is:

$$\lambda m = b/T \tag{2.6}$$

where λm is the wavelength (microns) of maximum radiation.

b is Wien displacement constant = 2897 microns ^{o}Kelvin.

T is the absolute temperature in ^{o}Kelvin.

Planck's radiation equation resulted from his investigations of the atomic oscillations in materials and of the statistical distributions of energies among various degrees of atomic freedom. Indications given by Wien's law and Stefan-Boltzmann law, in addition to his experiments, indicated the possibility of describing the blackbody radiation curves by a mathematical equation. He reached the conclusion that the interchange of radiant energy between two bodies was not a continuous process but that it was taking place because of distinct units of energy called "quanta" which are equal to the product of the frequency times a constant called Planck's constant. His final solution for blackbody radiation is formulated by:

$$W_{\lambda} = C_1 \lambda^{-5} \left[e^{C_2/\lambda T} - 1 \right]^{-1} \tag{2.7}$$

where W_{λ} = radiant flux emitted per unit area per unit increment of wavelength; watts/cm^2/micron.

λ = wavelength in microns

e = 2.71828

T = absolute temperature in ^{o}K

$C_1 = 2\pi c^2 h = 3.740 \times 10^{-12}$ watts cm^2.

$C_2 = hc/k = 1.438$ cm^{o}K

c = velocity of light (2.99793×10^{10} cm/sec)

h = Planck's constant (6.6252×10^{-34} watt sec^2)

k = Boltzmann's constant (1.38042×10^{-23} watt sec/^{o}K)

These equations are fundamental to the understanding of infrared radiation measurements.

For better understanding of the radiation phenomena at the surface of the ground, let us consider the sun as a source of radiation and the phenomena taking place along the path before it reaches the ground.

Atmospheric absorption phenomena will considerably alter the radiation from the sun. If we apply Wien's Law to the sun's temperature of $6000^{\circ}K$, we will find a peak radiation wavelength at 0.482 micron. On Figure 11, this peak radiation wavelength would occur to the extreme left of the figure. On the other hand, for an estimated ground temperature of $288^{\circ}K$ (15° Celsius) the peak would be very close to 10 microns; of course the total radiation (surface under the domed curve) is considerably reduced. Figure 11 shows intermediate temperatures between these extremes.

When considering what happens to the sun's radiation as it passes through the atmosphere, one notices that besides the fact its intensity is considerably reduced, the radiation is absorbed preferentially. The atmospheric gases absorb the sun's energy at characteristic wavelengths or wavelength ranges.

Figure 12 is a graphical representation of this absorption phenomena. Thus, instead of having a bell-shaped smooth continuous curve of solar radiation with its peak at 0.482 micron, we have an irregular curve, each of the lows corresponding to an absorption band. The highs correspond to high transmission bands, or most often are referred to as "windows" in the spectrum.

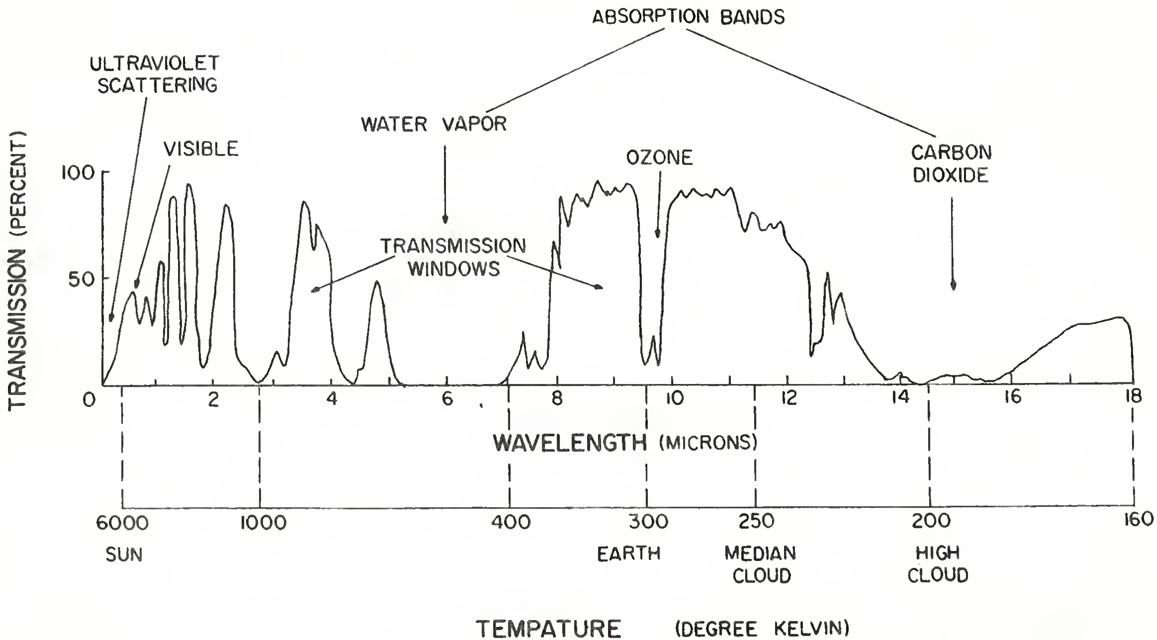

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FIGURE 12 HORIZONTAL TRANSMISSION THROUGH THE ATMOSPHERE AS A FUNCTION OF WAVELENGTH, WITH TEMPERATURE OF VARIOUS BLACK-BODY SOURCES AND THEIR PEAK EMISSION WAVELENGTH.

The earth's atmosphere thus absorbs at specific wavelength according to the gases it contains; principally water vapor, ozone (O_3) and carbon dioxide. Depending upon factors like the path length, the precipitable water vapor, the overall weather, the altitude, the concentration and size of aerosols, the atmospheric transmission, the absorption will vary greatly. This has been investigated by several climatologists, meteorologists and other scientists. Yates and Taylor [appendix of 107] have studied some of these variables and prepared numerous atmospheric transmission spectra from 0.5 to 15.0 microns. These atmospheric conditions are important not only in the design of infrared detectors for aerial surveys, but also for flight planning and interpretation of the imagery. For this reason some of Yates and Taylor's curves were combined in order to present the results in a more useful manner.

Figure 13 is a composite of transmission curves which indicates a reduction in both the visible range and infrared range, as the amount of precipitable water increases.

Figure 14 shows similar absorption phenomena for the infrared range, in the case of a longer path, but not in the visible. The daylight visual range seems to be of greater use in defining transmission in the visible than the precipitable water vapor.

Figure 15 indicates that for similar amounts of precipitable water vapor, the path length reduces the percent transmission in both ranges. This is also the case for two different altitudes as is shown on Figure 16. The percent transmission at high altitude is increased, all other conditions being kept relatively similar (compare Figure 15-a and 16-a).

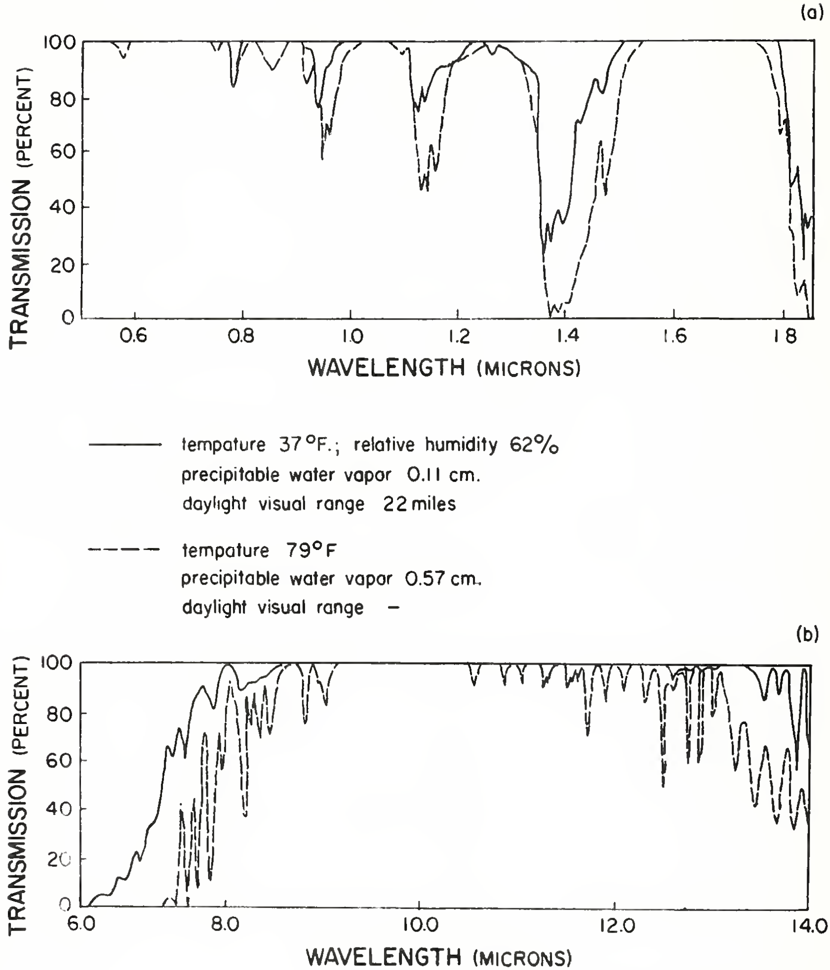

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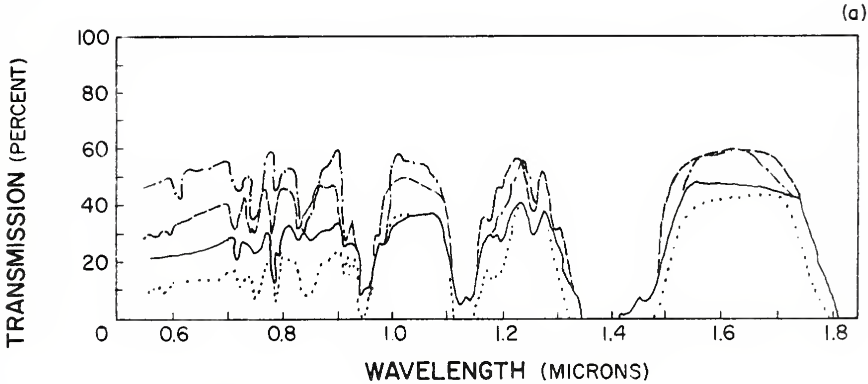
FIGURE 13 ATMOSPHERIC TRANSMISSION FOR A 1000 FOOT PATH AT SEA LEVEL, AS AFFECTED BY WATER VAPOR.



LEGEND	——	– – –	—·—	······
path (miles)	10.1	10.1	10.1	10.1
tempature (°F)	40.5	5.3	69.0	74.0
relative humidity (%)	48.0	41.0	53.0	82.0
precipitable water vapor (cm.)	5.2	6.7	15.1	27.7
daylight visual range (miles)	24.0	33.5	37.3	13.7

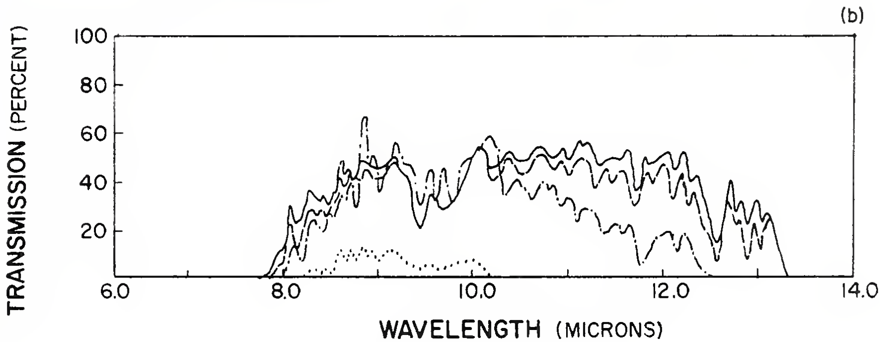


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FIGURE 14 ATMOSPHERIC TRANSMISSION FOR A 10.1 MILE PATH AT SEA LEVEL, AS AFFECTED BY WATER VAPOR.

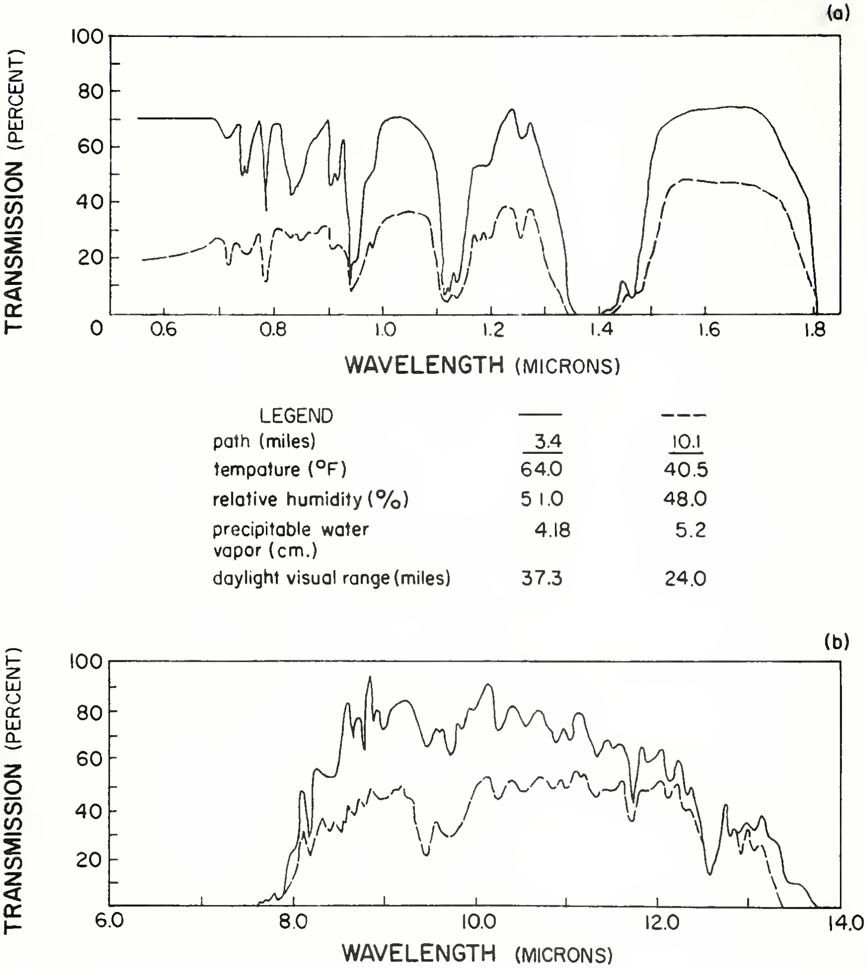

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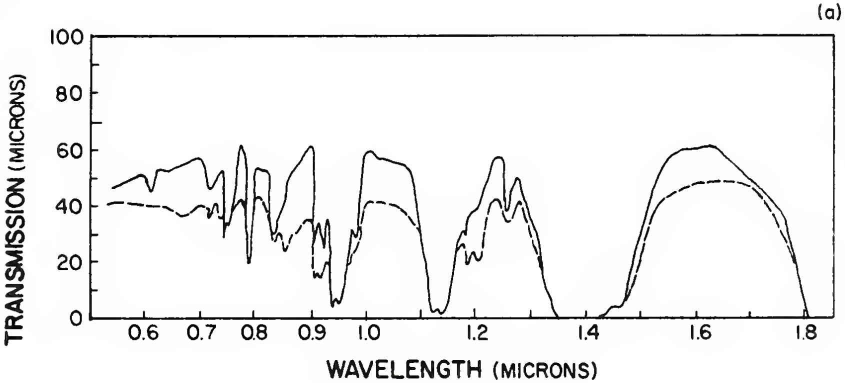
FIGURE 15 ATMOSPHERIC TRANSMISSION FOR TWO DIFFERENT PATH LENGTHS AT SEA LEVEL.



LEGEND	—	- - -
path (miles)	10.1	17.2
tempature (°F)	69.0	–
relative humidity (%)	53.0	–
precipitable water vapar (cm)	15.1	13.0
daylight - visual range (miles)	37.3	77.6

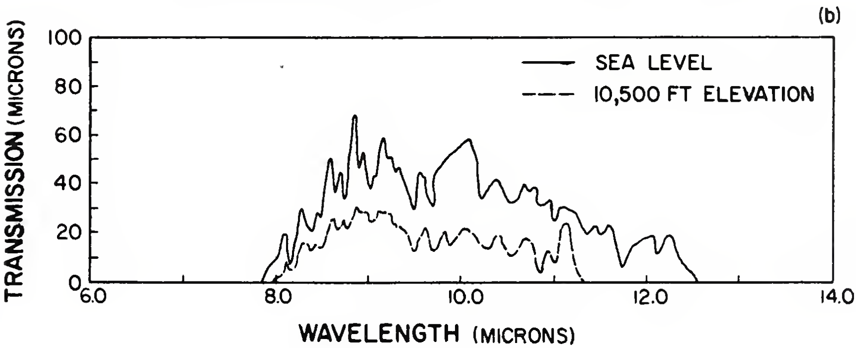


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FIGURE 16 ATMOSPHERIC TRANSMISSION FOR TWO DIFFERENT PATH LENGTHS AT TWO ALTITUDES.

Scattering phenomena by particles in the atmosphere will also alter the sun's radiation as it reaches the ground. Scattering phenomena are a function of the wavelength, the size and concentration of particles (aerosols) and also on their energy level.

Rayleigh and Mie scattering phenomena are described in physics and meteorology textbooks [121, 190]. They were reviewed by Rib [211]. Nonselective scattering occurs for larger particles (greater than 10λ) and all colors scatter equally well, thus producing white appearance as for clouds. Water vapor and in certain cases smoke and dust may produce nonselective scattering. Generally the practice is to measure the amount of precipitable water vapor in a path length and refer to tables to find the transmission of the path, and neglect the effect of smoke and dust. The important factors here are the diameter and the density of the particles.

Other factors relative to the atmosphere and its influence on wavelengths are treated in textbooks on atmospheric physics and meteorology. They will not be further discussed here but some should be listed because of their importance: atmospheric turbulence and thermal currents, atmospheric refraction and contrast attenuation of the scene, path luminance as a function of viewing angle, energy balance at the earth-atmosphere boundary, and soil conductivity [220, 190, 115, 107].

2.42 Multispectral Aerial Scanning Equipment and Sensors

This section is devoted to a brief description of the aerial scanning equipment available today and generalities on how the data is collected. The principal types of aerial scanners available today are: The Bendix Thermal Mapper [32], The HRB-Singer Reconofax Scanner [92, 92], and the PROJECT MICHIGAN Multichannel Scanner [105-a].

These instruments are essentially based on the same principle and they use the same method of object-plane scanning [107]. This technique is illustrated on Figure 17. It shows a conceptual view of a scanner in an aircraft flying over an area and covering the scene in a series of parallel strips. The scanning mirror rotates inside the aircraft and looks at the scene from right to left or from 'a' to 'b'. The surface 'cdef' is called the Instanteneous Field of View (IFOV) or resolution patch and its size is controlled by the optics of the system and the size of the detector. The forward motion of the aircraft allows the rotating mirror to advance and produce a raster covering a swath of ground. The geometry, the mirror rotation speed and the speed of the aircraft are inter-related.

The width of the scan strip is directly proportional to the altitude of the aircraft above terrain and to the IFOV. For a complete coverage of the area, the minimum line scan rate is inversely proportional to the altitude and the angular field of view. It is directly proportional to the ground speed, if a linear repetitive scan is assumed [93].

$$n = \frac{v}{h\alpha} \qquad (2.8)$$

where n = line scan rate (in lines per sec)

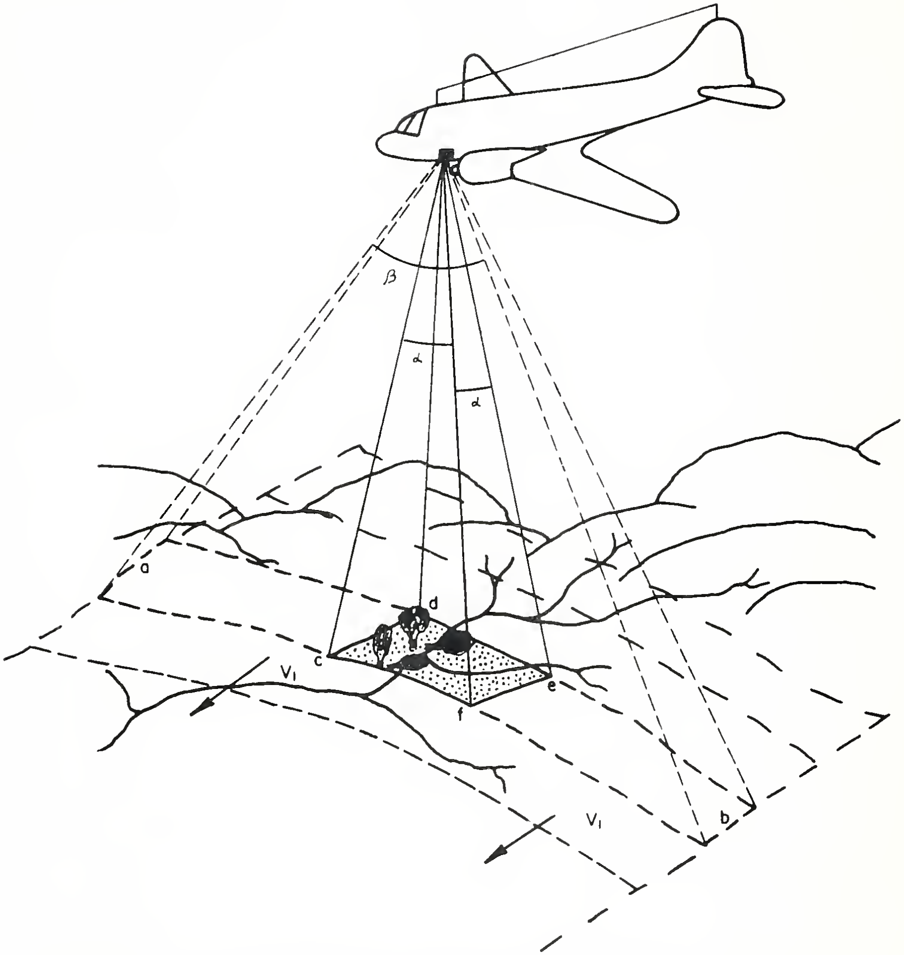


FIGURE 17. SCHEMATIC VIEW OF SCANNING PATH.

v = ground speed (in feet/sec)

h = altitude of aircraft (in feet)

α = instantaneous angular field of view (in radians)

The number of consecutive elements scanned per second is given by

$$N = \beta n/\alpha D \qquad (2.9)$$

where N = scanned elements per second

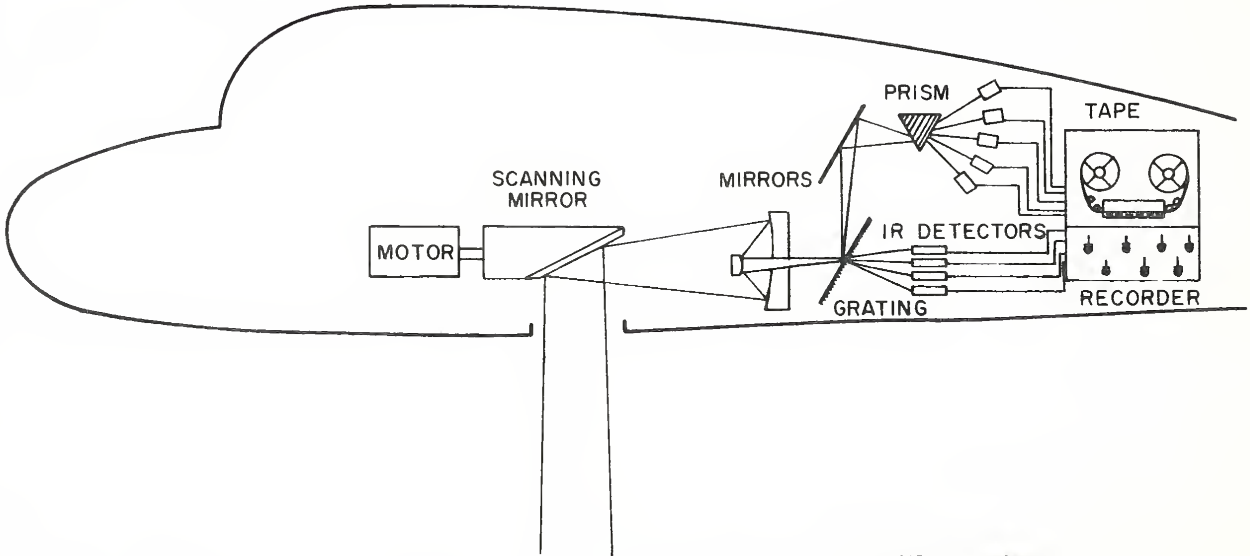
β = total angular field of view (radians)

D = line scan duty

If the aircraft speed is such that the scan lines do not touch each other this produces an underlap condition. If the scan lines superimpose, the aircraft is going too slow and this produces an overlap condition. It is the general practice to have the scan lines slightly overlapping when imaging the data. There is always some overlap towards each end of the scan lines, because the geometry is not as simple as implied above: in other words, the value of h varies with the sight angle.

The scanner rotation rates, geometry and operation requirements are explained in Holter et al. [107]. General information on scanner geometry and design considerations can be obtained from the following references: [106, 108, 235, 97, 189, 104].

When the aircraft flies over an area and the optical-mechanical scanner is operating, the radiation from the scene is collected by the optical system composed of the rotating mirror (see Figure 18) and by a Cassegrainian optical set of mirrors which converge the radiation onto what is illustrated as a mirror-grating assemblage. This is where the infrared radiation is separated from the visible. The visible portion



MODIFIED AFTER LARS

FIGURE 18. CONCEPTUAL SINGLE APERTURE MULTISPECTRAL SCANNING EQUIPMENT.

is further divided into narrow bands of the spectrum. Each band of interest is collected through an optic-fiber bundle in front of a photomultiplier tube which produces an electrical signal. This signal is recorded on a magnetic tape in the case of the Michigan scanner. The system is comparable to a regular scanner for which the normal single detector has been replaced by a spectrometer slit, thus permitting to collect "multiband" data.

The infrared radiation in the Michigan scanner is processed in a somewhat similar manner, except that the detectors are not photomultiplier tubes but are semiconductors generally referred to as thermal sensors. The Michigan scanner normally collects information in 18 possible narrow bands. In fact, the scanner uses four heads as the one shown on Figure 18. Each of these four apertures collects the information as follows: one channel in the ultraviolet (UV); twelve channels in the visible; four channels in the near-to-middle infrared; one channel in the far infrared [132]. For this project, only 15 bands were used; 3 bands in the infrared region were not operative.

Ultraviolet	0.32 - 0.38 micron	Visible	0.58 - 0.62 micron
Visible	0.40 - 0.44		0.62 - 0.66
	0.44 - 0.46		0.66 - 0.72
	0.46 - 0.48		0.72 - 0.80
	0.48 - 0.50		0.80 - 1.0
	0.50 - 0.52	Infrared	4.5 - 5.5 microns
	0.52 - 0.55	Infrared	8.0 -13.5 microns
	0.55 - 0.58		

The Bendix Thermal Mapper is described by Blythe [32] and Blythe and Kurath [33]. It produces imagery in the 3.5 to 5.5 micron region and uses an InSb detector. It is a relatively light instrument that uses a glow tube to expose a 70 mm. strip film as the radiation is collected [97]. This scanner is not classified and is available on the

market. A version sensitive in the 8-14 micron band is also available.

The HRB-Singer Reconofax scanner takes imagery in two different bands, one at a time. It uses either a InSb sensor for the 4.5 to 5.5 micron band or a Ge:Hg sensor for the 8-14 micron band. Imagery is produced by a glow tube on 70 mm. film strip [93, 97]. There is an advantage to this system in that it produces imagery in real time or very close. The U.S. Forest Service uses the system with a film strip and/or Polaroid prints and drops these to the fire bosses through a specially designed drop tube ejector. The information is delivered in 1 hr. 40 min., from the first imagery run to the completed map, allowing one hour for the flight and 40 minutes for the information to be transferred onto a map. This is not a classified instrument and it is available commercially.

The Project Michigan scanner data is recorded in a different manner. Figure 19 is a conceptual view of what is done to the information once it is collected on the magnetic tape. The analog tape can be processed in different ways. This figure shows the two possibilities used in this project. The upper part of the figure indicates what happens when the tape information is displayed through a cathode ray tube (CRT) and is exposed on a film strip through an appropriate set of lenses. This method is also illustrated on Figure 20. It shows the in-flight recording method which is essentially what was used for the film strips obtained for this project.

The analog information on the tape has many advantages. It is a near-real-time method and it can be used for investigating the problems of optimum control and presentation of scanner video data on film strips.

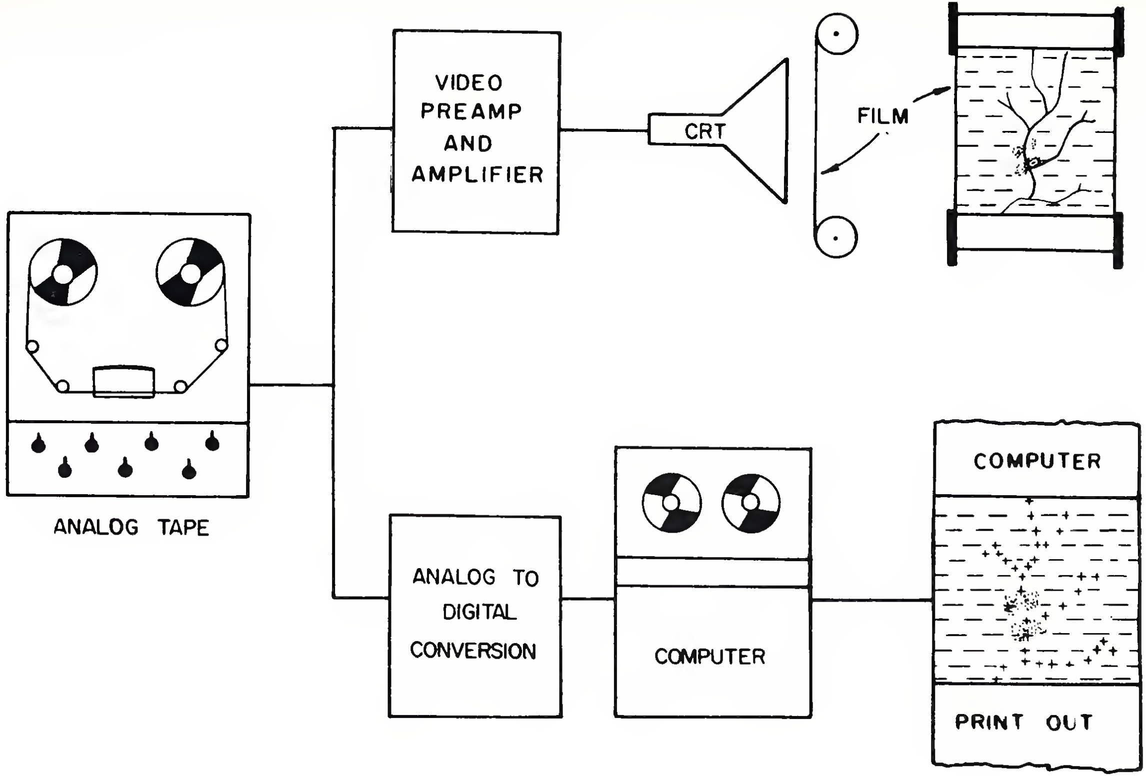


FIGURE 19. PROCESSING METHODS OF ANALOG DATA FROM SCANNER

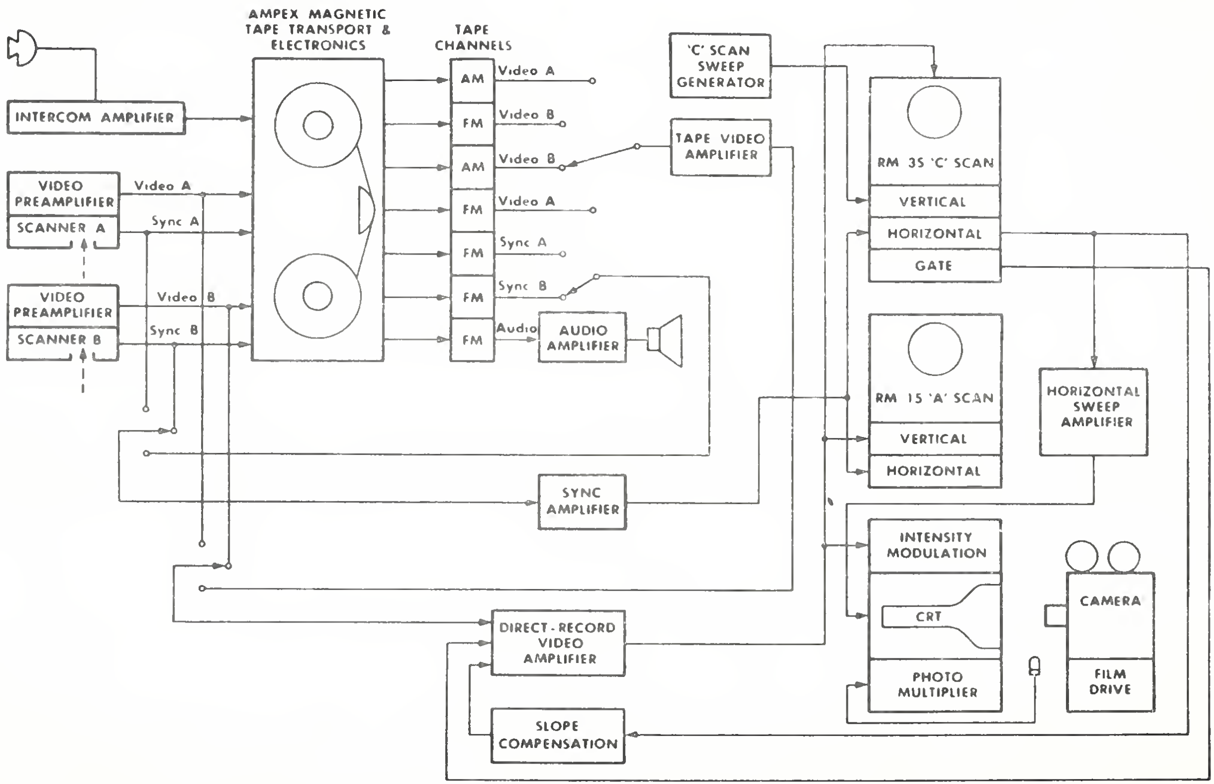


FIGURE 20. BLOCK DIAGRAM OF IN-FLIGHT IR-SCANNER RECORDING SYSTEM (England et al. 1966)

By sophisticated techniques and successive play backs, the imagery can be selectively enhanced by using either filters, differentiating networks, high frequency boosting and delay lines or combinations of these. England and Morgan [72] refer to the C-Gate technique where the signal is quantitatively compared with a simultaneous radiometric measurement line-trace and a densitometer trace along a corresponding part of the final output film. This research may result in a more accurate method for future quantitative approach to the problem of scanner imagery display.

The second method of displaying the imagery is as shown on the lower part of Figure 19. The analog tape is converted to a digital tape and the data is reformated [127]. Each scan line is given a line number and is divided into 221 columns. This is done for locating information during computations and also for reading the computer printouts.

After the analog to digital conversion the resulting tape can be used directly for imagery classification by the use of the LARS computer system programs. This method will be further described in Chapter 5, when presenting the results of automatic classification [125, 127, 237, 123, 124, 126].

Returning to the detectors and the variables affecting the multispectral data collection, it was said that the radiation from the scene in the visible range, is collected in a more or less conventional way by photomultiplier tubes, but the infrared radiation is not. Special infrared sensors of various types are used for this purpose. Figure 21 indicates some of the possible thermal sensors generally used for either airborne surveillance or for field data collection (ground truth). The sensors being discussed here are the ones used in the multispectral

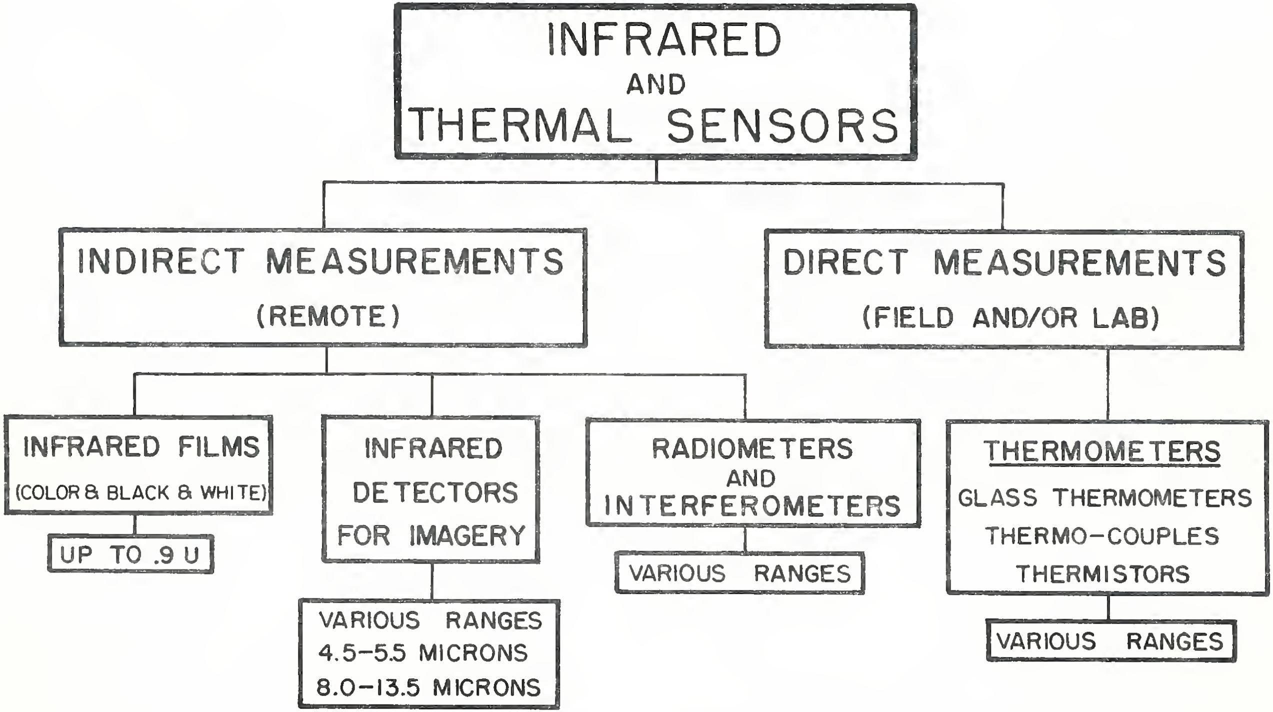


FIGURE 21. INFRARED AND THERMAL SENSORS

infrared imagery (see second box from the left).

In the range of thermal infrared the airborne sensors use special detectors which are for practical purposes semiconductors used as transducers of the infrared radiation. These detectors are generally cooled off at low temperatures to increase their "detectivity". Figure 22 shows the characteristic detectivity curves of some detectors. The tendency is to use the InSb detector for the 2.0-5.0 micron range, and the Ge:Hg detector for the 8-14 micron region.

It is important, in order to interpret the imagery from these detectors in a coherent manner, to know what factors may influence the imagery collection. The factors involved are related to (1) the detector used and its characteristics, (2) the scanner operation and its design, (3) the radiation source and properties, (4) the meteorological conditions prevailing at the time of the mission.

The detector characteristics are described by Holter et al [107]. They include:

1 - the responsivity level and spectral responsivity

2 - the internal detector noise level

3 - the response time (time constant)

4 - the dynamic range

5 - the stability or ability to hold calibration

6 - the size and shape

7 - engineering advantages (simplicity, cost, uniformity of production, shelf life).

Of all these, the most important characteristics are the size of the detector, its time constant and the response bandwidth. A simple

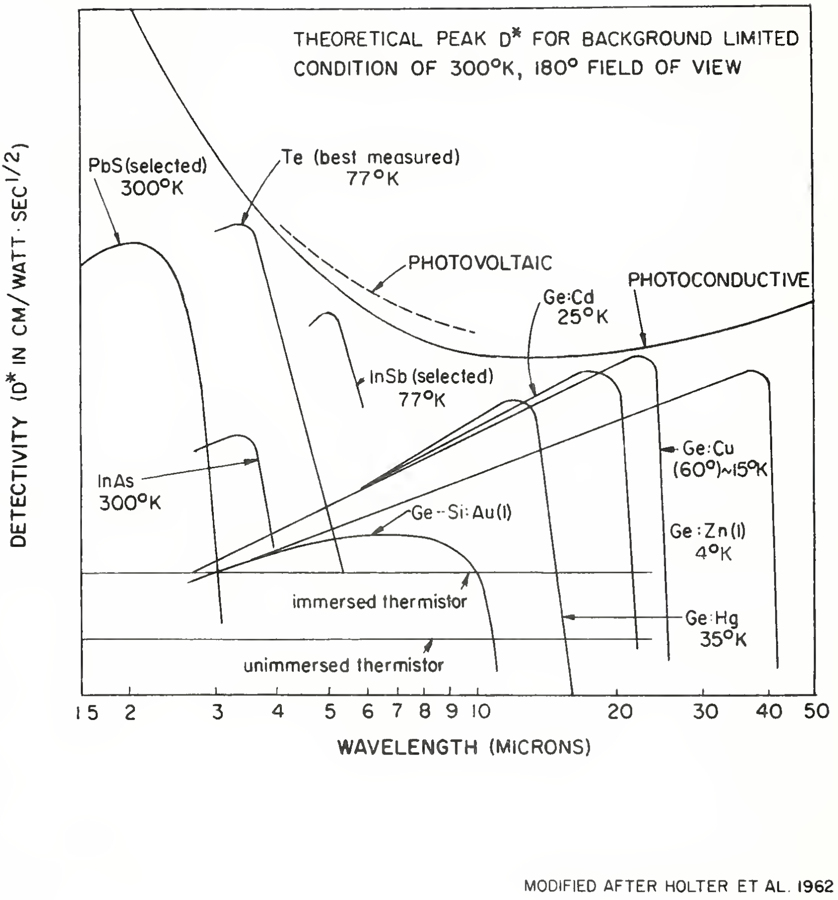


FIGURE 22 DETECTIVITY D* OF SOME INFRARED DETECTORS, IN THE BACKGROUND NOISE-LIMITED CASE.

conventional way of rating detectors is the Noise Equivalent Power (NEP) detector classification scheme. This is to establish comparisons between detectors as a function of their properties and the operating conditions. Three different detectors are compared on that basis in Figure 23, for different signal-to-noise ratios [73]. This figure indicates that depending upon the scene temperature a certain detector may be more desirable. For instance, in forest fire detection, in which case the temperatures are such that the peak wavelength is shifted from the normal 8-14 region to the 2-6 micron region, a Indium antimonide (InSb) detector would be preferable.

The meteorological conditions prevailing are also important. High velocity winds would tend to destroy the temperature differences over the scene in cooling off all its components. The influence of haze and particularly fog is considerable. Figure 24 illustrates how the transmission coefficient is decreased as the visibility decreases. It suggests that unless the visibility is in the order of 20 miles or more, the infrared mission results can be hampered considerably. This is also illustrated in Figures 25 and 26 for different regions in the spectrum and for different sensors. These results adapted from Feder [73] are shown here for the purpose of indicating the importance of weather conditions for infrared missions.

The geometry distortion introduced in the imagery at the time of scanning is an important consideration. Figure 27 shows an example of what is meant by distortion. Notice that the central two thirds of the resultant imagery is nearly distortion-free. It is only on the extreme edges that shapes are really deformed beyond recognition. Depending

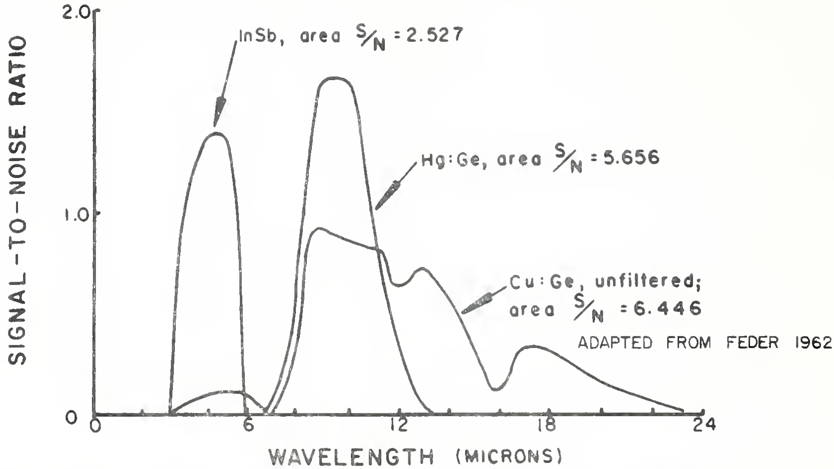


FIGURE 23. SIGNAL-TO-NOISE AS A FUNCTION OF WAVELENGTH FOR A 300°K BLACK BODY. $\Delta T = 1°C$ FOR ATMOSPHERE CONTAINING 17 MM OF PRECIPITABLE WATER AND CARBON DIOXIDE.

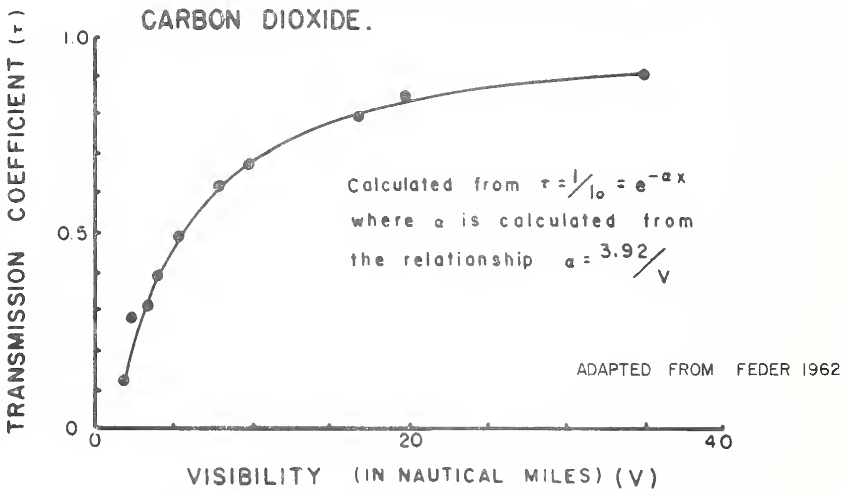


FIGURE 24. TRANSMISSION COEFFICIENT VERSUS VISIBILITY THROUGH FOG FOR THE INFRARED SPECTRUM OVER A ONE NAUTICAL MILE PATH.

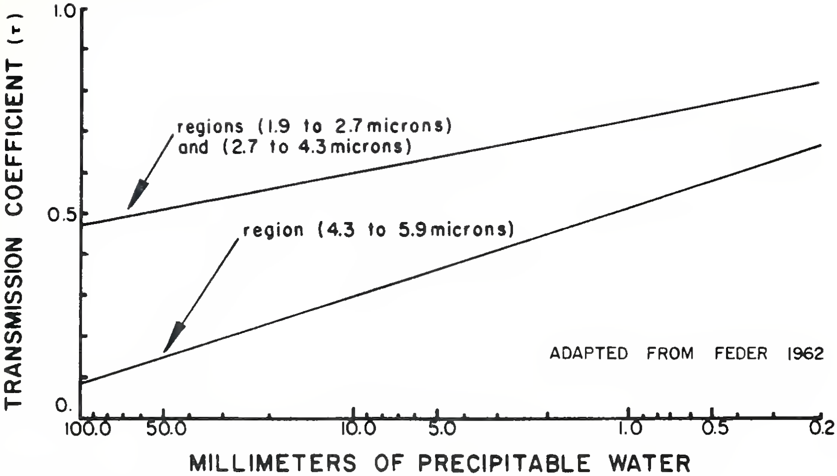


FIGURE 25. AVERAGE TRANSMISSION COEFFICIENTS AS A FUNCTION OF WATER VAPOR FOR DIFFERENT REGIONS OF THE SPECTRUM.

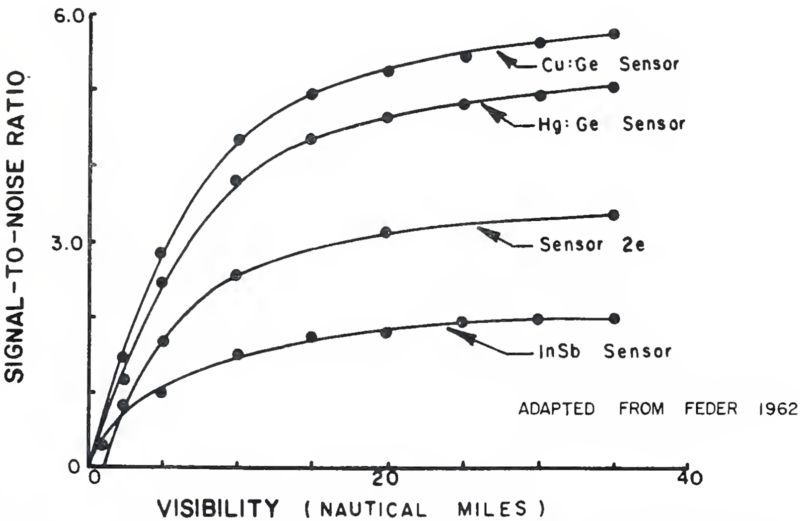
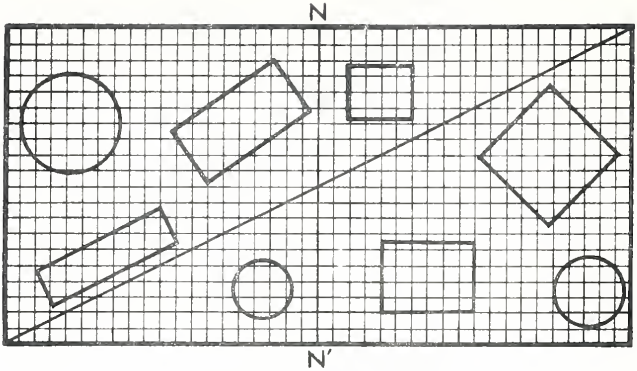
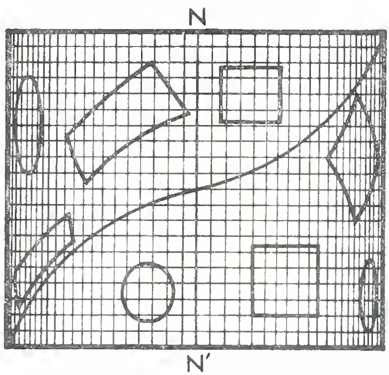


FIGURE 26. SIGNAL-TO-NOISE RATIOS OF INFRARED SYSTEMS AS A FUNCTION OF THE TRANSMISSABILITY OF A ONE NAUTICAL MILE PATH OF THICK FOG.



Terrain assumed flat
N-N' = nadir line



Resultant geometry distortion

ADAPTED FROM LATMAN ET AL., 1965

FIGURE 27. GEOMETRIC DISTORTION DUE TO SCALE COMPRESSION ON THE MULTISPECTRAL IMAGERY

upon the use of the imagery this distortion may be critical but if the intensity of the response is to be used only, then the distortion is of secondary importance.

This distortion is due to the fact that for the scanner, the angular resolution is constant but the linear ground resolution is not. It varies as the angle of view increases away from the vertical. Figure 28 shows how the resolution element is distorted and enlarged away from the vertical. If θ is the angle away from the vertical, if a is the length of the IFOV in the direction of flight and r is the distance from the scanner to the ground at any instant, then $a = r\alpha$, $r = h \sec \theta$ and $a = \alpha h \sec \theta$. The other dimension of the IFOV will vary in the following manner (see lower part of Figure 28) [107, 64]

$$S_2 = h \tan (\theta + \phi) = h \frac{\tan\phi + \tan\theta}{1 - \tan\phi \tan\theta}$$

$$S_1 = h \tan (\theta - \phi) = h \frac{\tan\theta - \tan\phi}{1 + \tan\phi \tan\theta}$$

For small angles, $\tan \phi \approx \phi$ and

$$S_2 \approx h \frac{\phi + \tan\theta}{1 - \phi \tan\theta}$$

$$S_1 \approx h \frac{\tan\theta - \phi}{1 + \phi \tan\theta}$$

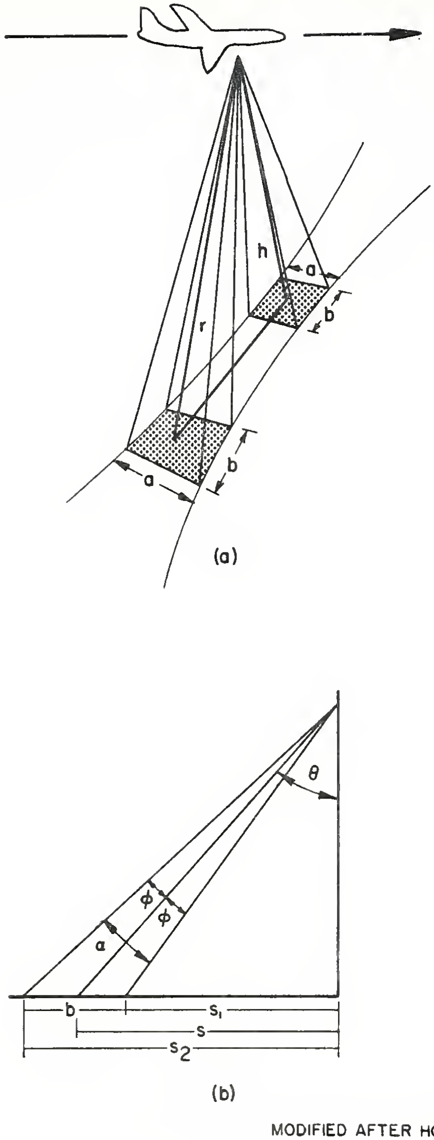
thus,

$$b = S_2 - S_1 \approx 2h\phi \frac{1 + \tan^2\theta}{1 - \phi^2 \tan^2\theta}$$

For $\theta < 85^\circ$, $\tan\theta$ is about 10. For ϕ of about 10^{-3} radian, $\phi^2 \tan^2\theta$ can thus be neglected and the expression becomes

$$b \approx h\alpha(1 + \tan^2\theta) = h\alpha \sec^2\theta$$

In summary, the two dimensions of the IFOV vary as



MODIFIED AFTER HOLTER ET AL. 1962

FIGURE 28 INSTANTANEOUS FIELD OF VIEW VARIATION.

$$a = h\alpha \sec \theta$$

and
$$b \approx h\alpha \sec^2\theta$$

Another consideration has to be made at this point. The processing or imaging of the data for the Michigan scanner is not a real time process. Although tape recorded signals are proportional to detector output voltage and the detector itself is a linear transducer from input flux intensity to output voltage, further amplification and recording (imaging) in the scanner system may introduce nonlinearities (see Figure 20).

The mode and delay which are used in processing the signal for producing imagery is quite significant in terms of contrast and sharpness of details. Figure 29 indicates some results of different waveforms [70].

Figure 29 indicates the influence for different waveform variations on the reproduction of an original square wave signal. By an appropriate combination of electronic processing the original signal is reproduced with greater fidelity; for instance, by addition of a differentiated AM signal delayed 25μ sec. (B) and a differentiated inverted AM signal delayed 10μ sec. (C) a composite waveform (D) is obtained. Additional boosting effect of an FM signal produces the F waveform. By increasing the FM signal somewhat more, waveform G is produced and is nearly equivalent to the original square wave before recording. This is shown to draw attention to the importance of signal processing and all the enhancement techniques available, that not only improve the imagery but in many cases may increase its significance. It is not possible to determine the enhancement characteristics of the imagery obtained for this project.

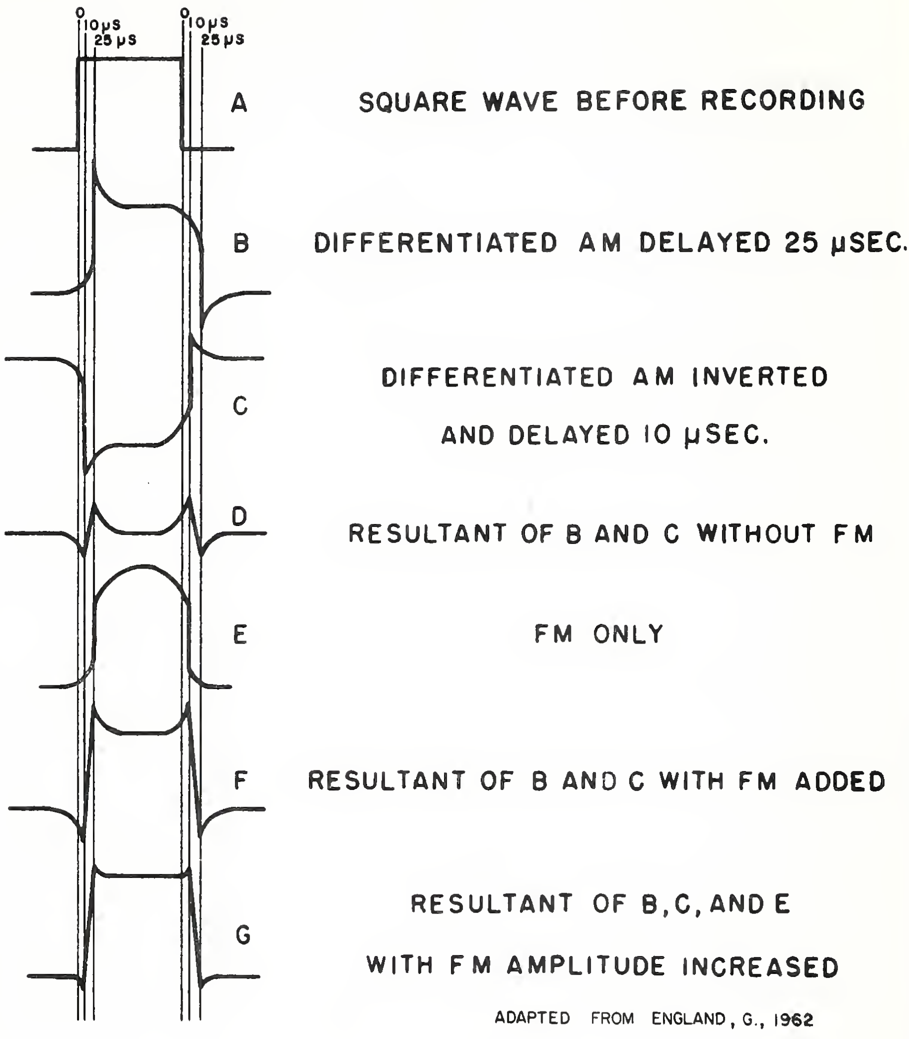


FIGURE 29. RESULTS OF WAVEFORM VARIATIONS ON CONTRAST AND SHARPNESS OF IMAGERY

2.43 Imagery Interpretation Methods

There are several ways in which imagery interpretation can be conducted. Figure 30 was prepared to show the techniques reported in the literature. It is divided in two main sections: the left one refers to conventional photo-interpretation techniques as they are generally applied to aerial photographs; the right one indicates some of the most recent automatic and semi-automatic approaches.

The technique of interpretation for aerial photographs is the approach most used to interpret infrared and multiband imagery, especially when only one, two or a small number of imagery bands are obtained. It is a qualitative approach and in certain cases is definitely the best approach (for instance forest fire detection on infrared imagery). Colwell [53] speaks of two schools of thought: one that considers the imagery as a photo-like image which requires highly subjective interpretation by a human analyst. The analyst must have the ability---"to apply obscure logic, far beyond any present machine capabilities." The second school maintains that recognition of an object from a photo-like image is done by observing its size, shape, shadow, tone and texture and other characteristics such as relative position. All of which, it is maintained can be adequately determined by a machine.

It might be useful here to point out some distinctions that have to be made. One is on the content of the interpretation. If only discrete objects, as is suggested here for the second school of thought, are to be identified, the problem is quite different than for a complete coverage of the entire content of either the photo or piece of imagery, as it would be for mapping soils.

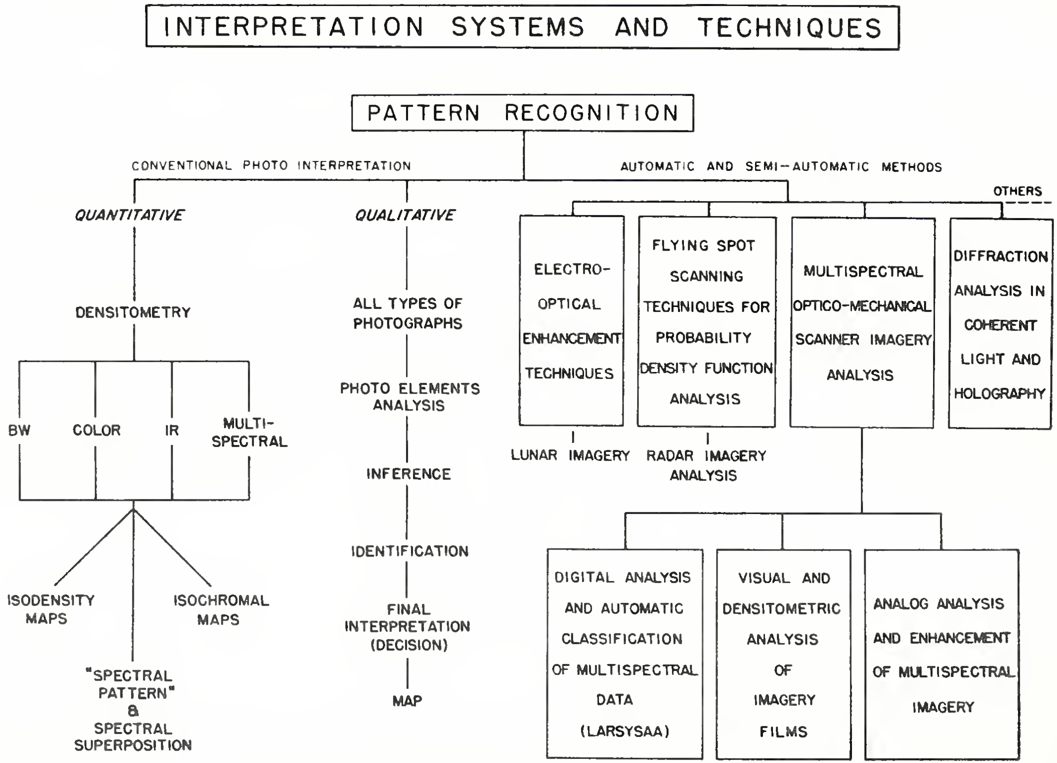

INTERPRETATION SYSTEMS AND TECHNIQUES
PATTERN RECOGNITION
CONVENTIONAL PHOTO INTERPRETATION
AUTOMATIC AND SEMI-AUTOMATIC METHODS
OTHERS
QUANTITATIVE
DENSITOMETRY
BW
COLOR
IR
MULTI-SPECTRAL
ISODENSITY MAPS
ISOCHROMAL MAPS
"SPECTRAL PATTERN" & SPECTRAL SUPERPOSITION
QUALITATIVE
ALL TYPES OF PHOTOGRAPHS
PHOTO ELEMENTS ANALYSIS
INFERENCE
IDENTIFICATION
FINAL INTERPRETATION (DECISION)
MAP
ELECTRO-OPTICAL ENHANCEMENT TECHNIQUES
LUNAR IMAGERY
FLYING SPOT SCANNING TECHNIQUES FOR PROBABILITY DENSITY FUNCTION ANALYSIS
RADAR IMAGERY ANALYSIS
MULTISPECTRAL OPTICO-MECHANICAL SCANNER IMAGERY ANALYSIS
DIFFRACTION ANALYSIS IN COHERENT LIGHT AND HOLOGRAPHY
DIGITAL ANALYSIS AND AUTOMATIC CLASSIFICATION OF MULTISPECTRAL DATA (LARSYSAA)
VISUAL AND DENSITOMETRIC ANALYSIS OF IMAGERY FILMS
ANALOG ANALYSIS AND ENHANCEMENT OF MULTISPECTRAL IMAGERY

FIGURE 30.

A second distinction should be made concerning "mono band" imagery (that is imagery obtained in one single discrete band of the spectrum, as is generally the case for infrared imagery from thermal scanner, or radar imagery) and multiband imagery for which up to 15, even 18 distinct film strips are obtained. No need to emphasize the difference in amount of data that has to be "looked at" in 15 different bands.

Thirdly, the purpose followed during the interpretation will have much consequence on how the interpretation is to be done. If it is for enhancement as opposed to simple delineation of "similar" areas, or if it is for automatic classification and for automatic interpretation, there will be as many approaches entirely different from one another and each being just as justified and valid as the other, due simply to the purpose followed. It will become evident in the case of multispectral imagery, for instance, that a human cannot "handle" fruitfully interpretation of more than 4 to 6 different bands, visually.

The standard photo-interpretation approach is the most common approach to infrared imagery interpretation and multispectral imagery as well. It is quite valid in terms of time and money but has definite limitation in terms of the total information that can be visually extracted.

Several good examples of imagery interpretation following this approach are found in the literature. They tend to show that each mission has its own relevant examples and its own specific points [32, 33, 193, 196, 258]. From these cases, it appears that two problems occur: one is the geometry distortion at the edges of the imagery, the second is the background of certain imagery interpreters who accede to

imagery interpretation sometimes without the slightest idea of what photo-interpretation techniques are. The first problem may be overcome by simply trying to live with the more useful central portion of the imagery strips or to wait until instruments are developed that will permit to correct for the geometry distortion, at the time of imaging the film strip [41]. The second problem is more critical. Photo-interpretation cannot be learned quickly and efficiently in a short time. One could summarize by saying that photo-interpretation is--experience, experience, experience. Even this does not help the beginner. It is by timely and efficient papers on the methodology of photo-interpretation, and also by short courses and seminars aimed at the need, that the situation may eventually be corrected [116].

Another approach is the densitometric analysis (extreme left and central lower right sections of Figure 30). This approach has been used in several cases of quantitative photo interpretation attempts [211]. This is an approach suggested for instance by Chaves et al. [43, 44]. It never quite performed as well as anticipated. In the case of multispectral and particularly thermal infrared imagery, the densitometric approach may yield interesting results in terms of calibration of the imagery against field temperature information [133, 146, 256].

It is to be noted on Figure 30, that all the interpretation techniques are based on some kind of pattern recognition. Dealing with the upper right portion of Figure 30, where four different methods are listed with possibility for others, it must be said that they generally rely very little if at all on standard photo-interpretation. In fact the final product may be so altered that it is beyond all photo-interpretation

logic. This is the case of the diffraction analysis in coherent light and the holography technique. The use of a laser beam striking a photograph to produce a diffraction pattern which can be subsequently analyzed, compared to other patterns or used to reconstitute the primary input (image) has been the subject of recent research [9, 31, 47, 66]. In this procedure, the diffracted image is the Fourier transform of the original image, that is, the information is now contained in terms of frequency rather than distance. The original pattern can be reconstituted. This process is called spatial filtering and allows for possible pattern enhancement.

Another approach to automatic and semi-automatic methods of interpretation is characterized by the numerous attempts to use electronic scanning devices to convert the spatial image (photo) to a temporal signal which can be processed by filtering, comparison and other methods of enhancement before it is displayed in an image form. The scanning, recording and display functions are generally performed by either a CRT flying spot scanner or laser beam. DiPentima [65] describes this method in the following terms:

> A CRT flying-spot scanner is used to scan the input image and convert it into an electric signal which describes the point-to-point density values of the photograph as a function of its light transmission at each point. The signal thus produced is processed for enhancement or target recognition purposes. Finally an output signal representing the enhanced image or indicating the spacial position of a detected target was generated and displayed on a CRT monitor or recorded on film by a CRT. (DiPentima 1968)

A similar approach is suggested by Dalke [59, 60], Rosenfeld [216, 217] and Kazmierczak et al. [118], Olson [197]. Such an approach is convenient for any aspect of the interpretation research as related to any particular subject; soils mapping, vegetation study and target

detection. The main problems are presently the relatively low resolution of the CRT, low dynamic range and distortions and nonlinearities which limit the value of the technique. Part of this is presumably solved by using a laser beam instead of the CRT.

An interesting and promising offshoot of the electro-optical techniques is the application of the CRT flying spot scanner to the study of probability density functions. This was used by Morain and Simonett [184] in the study of vegetation patterns on radar imagery. In this method, the imagery is scanned with a flying spot scanner coupled to a pulse height analyzer. Curves are obtained in which the X-axis represents the intensity derived by measuring film transmittance and the Y-axis is a plot of the frequency of occurrence of given film transmittances. Analysis of peak and shape matching of these curves provides information on the patterns of the imagery.

Before treating the multispectral imagery analysis, three other methods deserve some attention. One method is proposed by Darling et al. [61] and uses photo patterns that are recorded by a slow TV scan and digitized. These data then serve as an input to a digital enhancement and discriminant analysis program. The final product is a computer printout. Huntley [110] presented a variant of this in which the final product is a color CRT display.

Another proposition comes from Nichols et al. [192]. They describe a method of conversion of infrared images to visible color images. This is a new approach that could be extremely useful for field data collection and possibly for airborne surveillance, in that it gives a direct color image of the infrared radiation.

As indicated on the lower right part of Figure 30, multispectral imagery can be interpreted and analysed by at least three different techniques.

The first to be considered is the visual and densitometric approach which was discussed previously. This technique was used in this research project and the results are reported in a later section.

The second is the analog analysis and enhancement approach. This is the present approach used at the Willow Run Laboratories, the University of Michigan, to analyze the multispectral information. This method is documented in the literature [71, 105, 72, 144, 145, 143]. This approach has built-in advantages such as the use of the direct analog signal as collected. It also allows for calibration and enhancement techniques to be used [72]. It permits the changing of the dynamic range and the suppression of noise. This approach was not used in this research project.

The third approach to analysis of multispectral data is the digital and automatic spectral classification technique developed by personnel of the Purdue University Laboratory for Agricultural Remote Sensing (LARS). This method was used in this research and will be more extensively described in Chapter 4, where results are presented. Basically this method uses a computer to analyze the spectral reflectance of each resolution element in the different spectral bands. The analog data is first digitized and computer programs (system name is PICTOUT) print out the imagery gray levels for selection of representative areas called training samples. Another program (system name is LARSYSAA) performs the statistical analysis of the spectral response of each sample. This program

permits the selection of the best combination of 2, 3 or 4 bands to be used in the automatic classification and display. The computer is used to perform the classification and to develop a display of the data on a printout format [125, 127, 237].

The LARS method is totally independent of intermediate photographic prints or films. The other techniques described previously are dependent upon film and prints. The classification is automatic but trained personnel and sufficient ground information must be available. The technique represents the most important advance in terms of automatic interpretation so far.

The need for ground truth in all of these automatic or semi-automatic methods of pattern analysis is emphasized. Unfortunately little is available in the literature on what constitutes adequate and useful ground truth. In general each case is a unique research program. No methodical approach is presented on ground truth collection.

A totally automatic interpretation system is not available at this time. The reader is referred to Figure 4, in which the phases of interpretation are listed. What has been done to date in terms of automatic interpretation is the analysis and recognition of shapes and forms in an automatic mode. Spectral patterns or signatures are also recognized and even identified relative to similar signatures but the significance or the final result of the interpretation is left to the interpreter or the analyst [46].

In terms of image enhancement, the same thoughts apply. Image enhancement is very useful for increasing the detection capabilities of the interpreter of things that could not even be seen before, but this

does not infer interpretation, let alone automatic interpretation, to be done by the simple fact of enhancement.

These considerations are not meant to point out the limited results but rather to encourage research efforts and most of all prevent misunderstanding of the terms pattern recognition and interpretation. The importance of further research on pattern recognition techniques is stressed for application to multispectral imagery, infrared imagery and radar imagery and for other considerations in aerial photography recognition techniques.

2.5 State of the Research on Remote Sensing

Remote sensing has emerged from two principal philosophies. One states that, in the past, only a very limited portion of the spectrum has been used. It is proposed that by using a wider range of wavelengths more information is gained and hopefully, multispectral signatures could be used to classify surfaces. The second approach is the attempt to collect the data on an electric signal form rather than a photo to permit an easier solution to the problem of automatic interpretation.

If one looks at the many attempts and promising results of remote sensing in the various fields of scientific and engineering activities, one is impressed by the diversity of potential applications and by the results themselves. Many examples are described in the Proceedings of the five Remote Sensing Symposia held at the University of Michigan.

So far the most outstanding applications of the infrared imagery have been in forest fire detection and mapping, geological studies of volcanic activities in Yellowstone Park and Hawaii, and coal fire detection [97, 162, 75, 226].

In multispectral data classification, the most outstanding results so far have been obtained by the LARS group. Their results are expected to be applicable in many different fields and will be made even more significant by the recent developments in scanner technology. A nine-band single aperture scanner is being tested by the Bendix Corporation. Another single aperture scanner is being designed for 24 different bands and was recommended by LARS, under research for a NASA-USDA* cooperative program [104]. Other developments are taking place in passive microwave sensing which may possibly yield interesting results. Holography techniques may also eventually become useful.

The discovery of a new technique is never immediately followed by its application. There always appears to be a certain lag. This was the case for aerial photography (1858) and its interpretation for engineering uses (early 1940's). Dr. Suits recently presented a synopsis of the evolution of remote sensing [236]. It is adapted and augmented in Figure 31 to illustrate that some of the recent techniques in remote sensing are so new that time and further research are required to pass the development phase and reach the applications stage.

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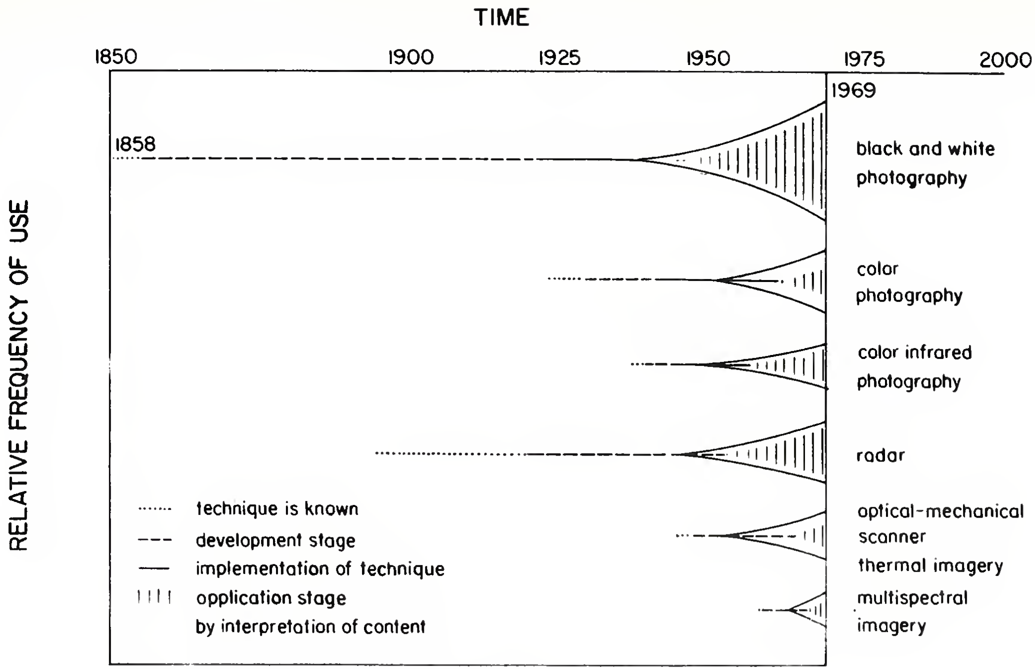
*NASA: National Aeronautics and Space Agency
USDA: United States Department of Agriculture.



MODIFIED AFTER SUITS 1968 AND AUGMENTED

FIGURE 31 EVOLUTION STAGES OF SOME REMOTE SENSING TECHNIQUES.

CHAPTER 3

ENGINEERING MASTER SOIL PLANS PROCEDURES

This chapter reports on the investigation of producing engineering master soil plans from different sources of information; geologic maps, pedological maps and from different types of aerial films, photographs, and multichannel imagery.

As indicated in the introduction, a section of 70 miles of highway in central Indiana served as the study area (see Figure 1). The section of State Road 37 extending southward from the southern edge of Indianapolis to Bedford presented an excellent area of study due to the variability of materials, of land forms and of geological conditions.

This section of State Road 37 is under study by the Indiana State Highway Commission for improvement and eventual construction to form a divided facility. At present, a by-pass to Martinsville is terminated (1968) and other short sections are being investigated for construction in the near future.

3.1 Method of Investigation

The preliminaries to this investigation included the contracting with the University of Michigan to obtain the multispectral imagery, the purchase of films and delivery to the ISHC photographic facilities, and the gathering and reading of the abundant literature on the area under study.

Besides the report of the first phase, written by Rib [211], the literature survey included one county engineering soils map for Monroe County (the only one available out of five counties involved) [261], five agricultural soils reports [39, 86, 241, 249], other pedological and related reports [109, 142, 255]. It also included geological reports and maps on the area of investigation [57, 85, 88, 208, 246, 252, 257]. The unpublished geological 7.5 minutes quadrangle maps of South-central Indiana were kindly made available to the author. They were extremely useful in preparing a compilation map of surficial geology.

In the early phases of this project, provisions were made for an early flight to produce a single flight line of black and white panchromatic photographs to be used to plan the subsequent phases. It was most useful in the field for ground truth acquisition. This photography was at a scale of 1000 feet to the inch and Plux-X panchromatic film was used.

Various other types of films were used on the subsequent flights and were exposed at lower altitude to procure photos at a scale ratio of 1:4800 or 400 feet to one inch. The type of film taken on the same day as the multiband imagery was the Kodak Ektachrome MS, developed as a negative because either black and white or color prints could be produced.

The other types of films used were: black and white, black and white infrared, natural color transparencies, and infrared color positive transparencies. These films were used for the following reasons:

1) The natural color transparencies were included as a backup for the natural color negative type film in case of processing or camera malfunctions.

2) The color infrared and black and white infrared were included

because of possible advantage in vegetation studies of importance in the interpretation of soils in this part of Indiana.

5) All of the various films were included in case the University of Michigan multichannel system could not be obtained. In preliminary contacts with them some equipment problems and priorities were indicated but by excellent cooperation of all concerned, the use of the equipment was finally made possible.

Black and white photos at a scale of 1:20,000 were ordered from the U.S. Department of Agriculture, to cover a strip of land approximately three to five miles wide by 70 miles long. These photos, dated from 1962 to 1967, provided recent coverage of the overall region over which the single flight lines were to be flown with the different films. This allowed for general land form - parent material study of the area and provided information for the detailed subsequent studies.

Valuable information was obtained from the agricultural soils reports and geological maps mentioned before and from field inspection. The equivalent of approximately eight days of field work were spent for the collection of soil samples and general field information, both prior to and after the day the maximum aerial information was collected, on April 28, 1967 (see Table 1, chapter 1). The field information consisted of hand auger bore holes, examination of road cuts and construction sites and observation of physiographic and topographic features that were relevant. The field work yielded the information required to prepare the soil profiles and to correlate these with the photo-interpretation and it provided soil samples for classification tests according to standard methods of testing. The results of classification testing

appear in appendix 1. The soil profiles are shown on the photo-maps.

3.2 Engineering Master Soil Plans from Various Sources

This investigation is concerned with the evaluation of the incremental information gain obtained by the use of different sources and sensor data. In chronological order of their development the following maps were produced.

3.21 General Land Form - Parent Material Maps

The first set of maps prepared during this study were produced from the 1:20,000 airphotos by standard photo-interpretation techniques and show land forms-parent materials distribution. They cover a strip of about 3 to 5 miles wide by 70 miles and are reproduced at a reduced scale on photo-maps 1 to 5 (Plates 1 to 5). They show, besides the land forms and the related soil profiles, the location of test holes, the location of special maps prepared at a larger scale are indicated by the word "map" followed by a number, and the areas of imagery studied by the use of the LARS computer approach are indicated by the word "area" followed by a number.

On these five photo-maps, the tentative route selected is indicated by a black and white narrow dashed strip [111, 112]. The special maps are indicated by white brackets, the computer interpreted areas by hatched brackets, and the bore-holes and soil profiles by white labels with the letter P followed by a number. The land form delineations are marked by continuous black lines and labeled with black symbols. The range and township lines, the section corners and section numbers are indicated in white numbers and letters.

LEGEND

FOR

INDIANA STATE HIGHWAY NO. 37
ENGINEERING SOILS MAPS

LAND FORM - PARENT MATERIAL CLASSIFICATION

LAND FORM CLASSIFICATION

A. Unconsolidated Material Land Forms

FLUVIAL LAND FORMS

Fp	Flood plain and major drainage ways
Fm	Minor drainage ways and narrow stream valleys
Fs, Fd	Swales and depressions on flood plains
Fo	Oxbows and meander scars on flood plains
Fk	Muck in depressions on flood plains
T	Terraces ; TL - Low terraces
A	Alluvial fans
C	Colluvial deposits

GLACIAL LAND FORMS

Gw	Ground moraine of Wisconsin age
Gi	Ground moraine of Illinoian age
Rm	Ridge moraine
Mk	Kame moraine (Wisconsin)
K	Kame
E	Esker
Gd	Depression; Gk kettle

GLACIOFLUVIAL LAND FORMS

Ow	Outwash and valley train deposits (Wisconsin)
Oi	Outwash and valley train deposits (Illinoian)
Od	Depressions on outwash

LACUSTRINE LAND FORMS

Lc	Lacustrine plain
Ld	Depression on lacustrine plain

EOLIAN LAND FORMS

S	Dunes (Includes silt mounds)
L	Loess plain

RESIDUAL SOIL LAND FORMS

R/Sh	Residual soils over shale and siltstone plain
R/Ls	Residual soils over limestone plain

B. Consolidated Material Land Forms

SEDIMENTARY ROCK LAND FORMS

Sh	Shale and/or siltstone plain
Ls	Limestone plain

Os. Sinkholes
Q Limestone quarry

SOIL TEXTURE CLASSIFICATION

1	Sands and gravels
2	Silty to clayey sands and gravels
3	Fine sands
4	Silty soils
5	Silty elastic soils
6	Clays
7	Clays (high plasticity)
8	Organic

DRAINAGE CLASSIFICATION

p	Poor (0-3 feet to ground water table)
i	Imperfect (3-6 feet)
g	Good (over 6 feet)

DEPTH TO BEDROCK CLASSIFICATION

1	Less than 3 feet to bedrock
2	3 to 10 feet to bedrock
3	More than 10 feet to bedrock

SLOPE CLASSIFICATION

f	Flat (0-3%)
m	Moderate (3-10%)
s	Steep (over 10%)

KEY TO SYMBOLS

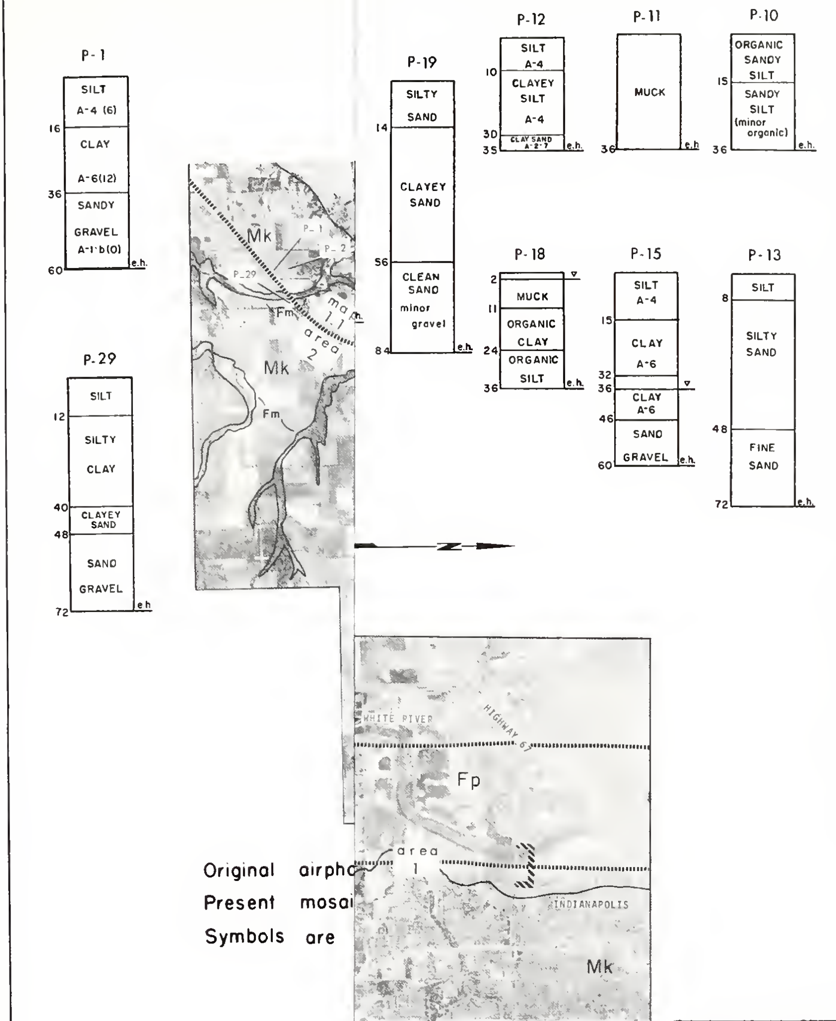
For all the symbols used, the first part is related to the land form, the second to the material testure, the third to the drainage condition, the fourth to the depth to bedrock, and the fifth to the slope condition.

EXAMPLES

Fp46p3f The land form is a flood plain (Fp) with parent material of silts and clays (46). Drainage is poor (p) with the water table between 0 and 3 feet most of the year. Depth to bedrock (3) is greater than 10 feet. The over-all topography is flat (f); all slopes are below 3%.

L:R/Sh or $\frac{L:R}{Sh}$ Loess (L) and/or (:) residual soil (R) over siltstone and shale (Sh)

FIGURE 32.



SOUTH

ATE AUG. 1968
by D.L.S.
00 dated '62-67
CKED by M.G.T.

AIRPHOTO INTERPRETATION & PHOTOGRAMMETRY LABORATORY
JOINT HIGHWAY RESEARCH PROJECT
SCHOOL OF CIVIL ENGINEERING

PURDUE UNIVERSITY

INDIANA STATE HIGHWAY NO. 37

ENGINEERING SOILS MAP

LEGEND

FOR

INDIANA STATE HIGHWAY NO. 37 ENGINEERING SOILS MAPS

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LAND FORM CLASSIFICATION

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S	Dunes (includes silt mounds)
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Sh	Shale and/or siltstone plain
Ls	Limestone plain

Sinkholes

Q Limestone quarry

SOIL TEXTURE CLASSIFICATION

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2 Silty to clayey sands and gravels
3 Fine sands
4 Silty soils
5 Silty elastic soils
6 Clays
7 Clays (high plasticity)
8 Organic

DRAINAGE CLASSIFICATION

p Poor (0-3 feet to ground water table)
i Imperfect (3-6 feet)
g Good (over 6 feet)

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1 Less than 3 feet to bedrock
2 3 to 10 feet to bedrock
3 More than 10 feet to bedrock

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f Flat (0-3%)
m Moderate (3-10%)
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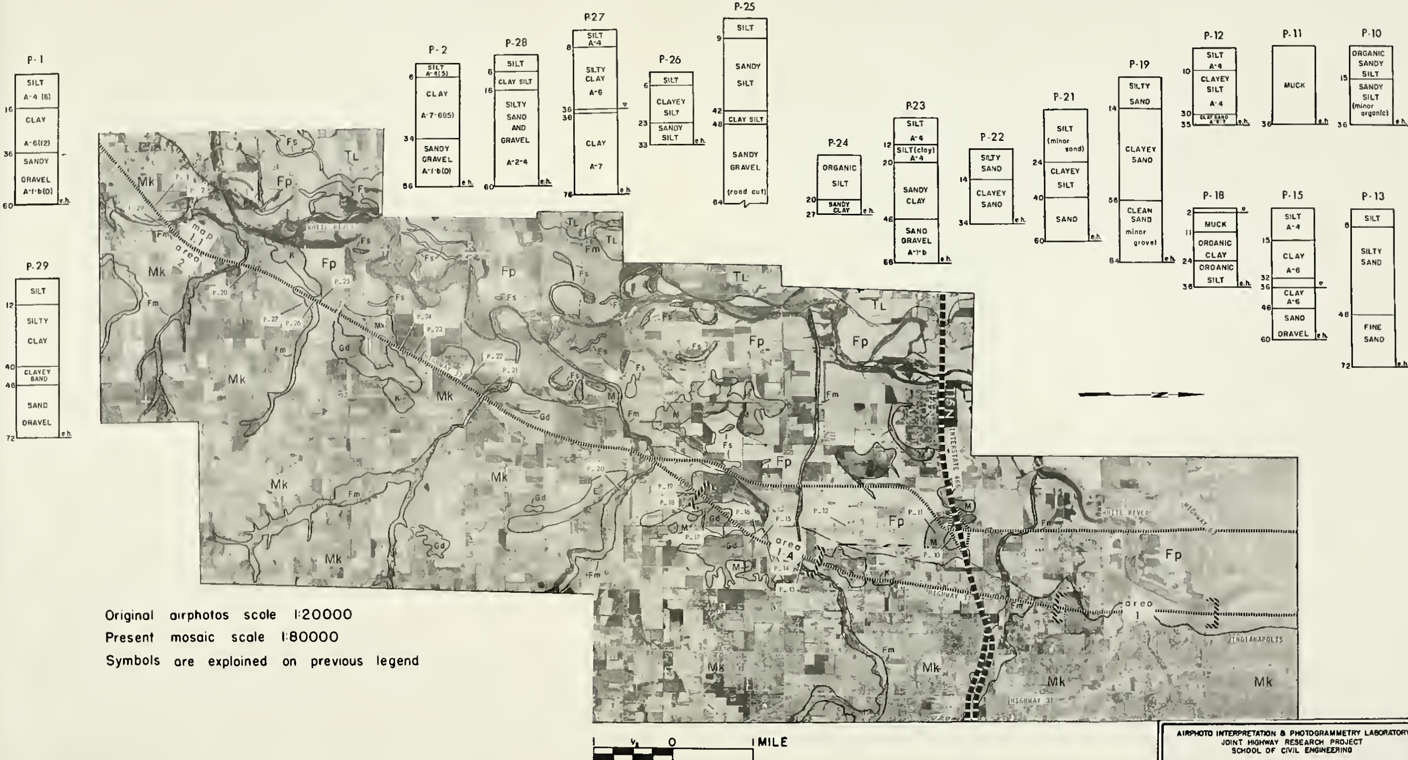
L:R/Sh Loess (L) and/or (:) residual soil

$\frac{L:R}{Sh}$ (R) over siltstone and shale (Sh)

FIGURE 32.



Original airphotos scale 1:20000
Present mosaic scale 1:80000
Symbols are explained on previous legend

SOUTH OF INDIANAPOLIS SEGMENT I

MAP SCALE 1:80000 SHEET NO. 1 of 19 DATE AUG 1966	
PHOTO INTERPRETATION by M.G.T. TRACED by D.L.S.	
AIRPHOTOS NOS. (USDA ASCS) at scale 1:20000 dated '62-'67	
FILM TYPE Pan PRINTS B&W FIELD CHECKED by M.G.T.	

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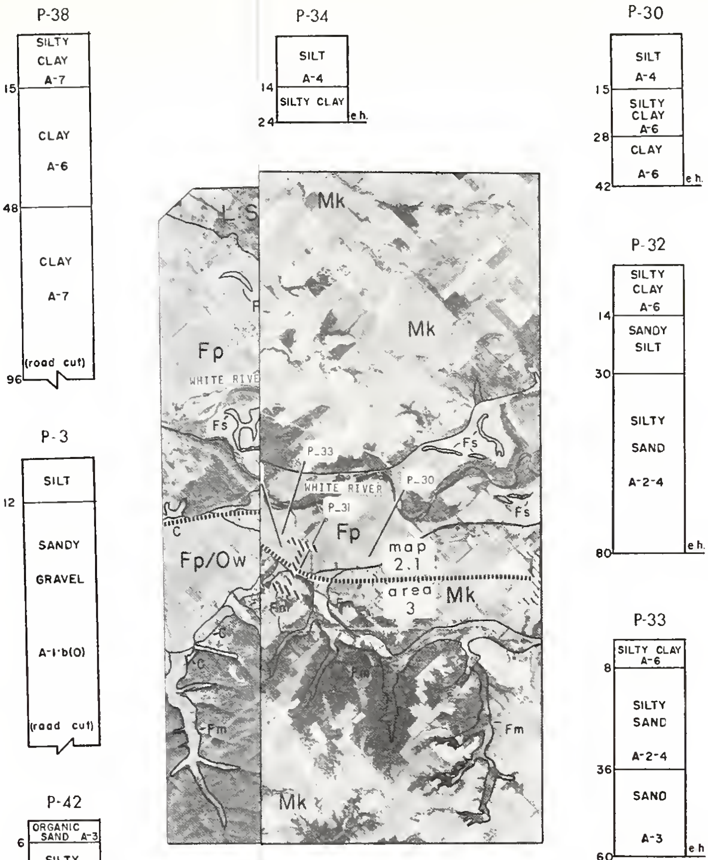
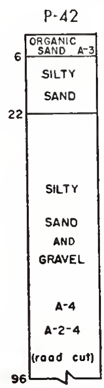
SCHOOL OF CIVIL ENGINEERING
PURDUE UNIVERSITY

INDIANA STATE HIGHWAY NO. 37
ENGINEERING SOILS MAP





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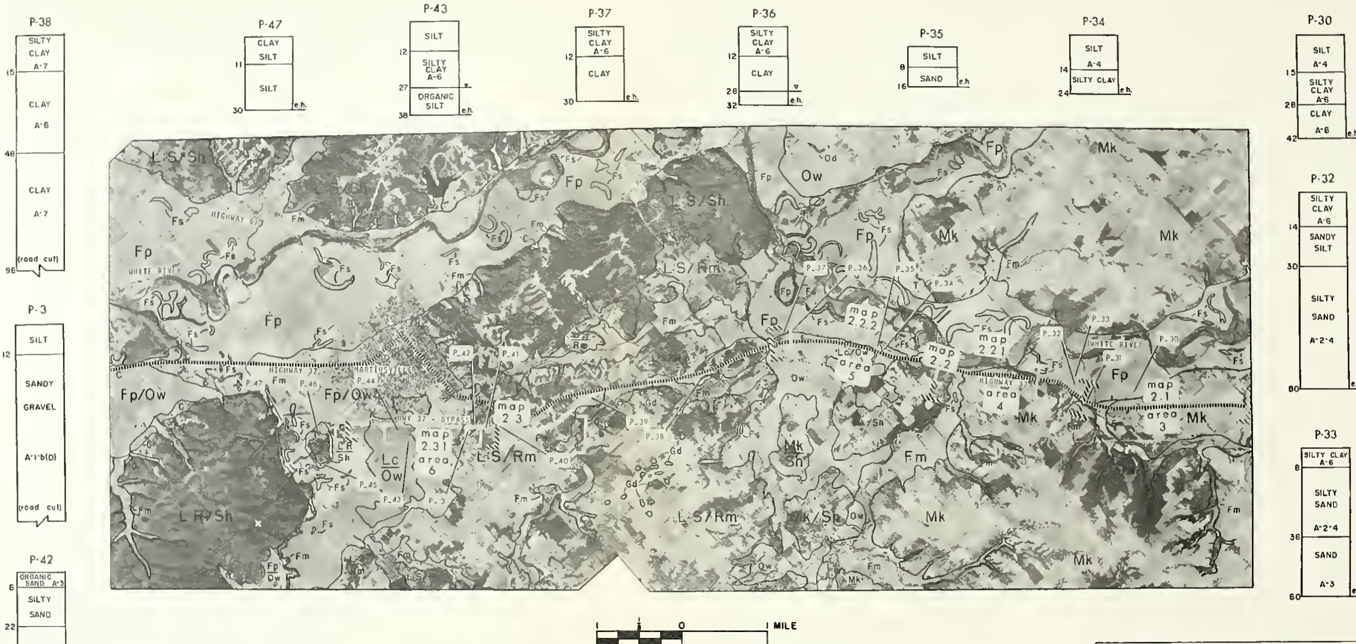
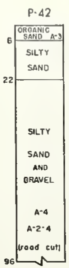
INDIANA STATE HIGHWAY NO. 37

ENGINEERING SOILS MAP

MAP SCALE 1:80,000	SHEET NO. 2 of 19	DATE Aug. 1968	
PHOTO INTERPRETATION by MGT	TRACED by D.L.S.		
AIRPHOTOS NOS. (USDA – ASCS)	at scale 1:20000	dated '62-67	
FILM TYPE Pan.	PRINTS B & W	FIELD CHECKED by MGT	





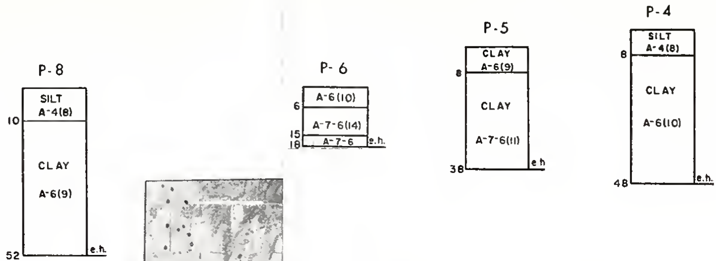
MARTINSVILLE SEGMENT 2

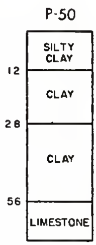
Original airphotos scale 1:20000

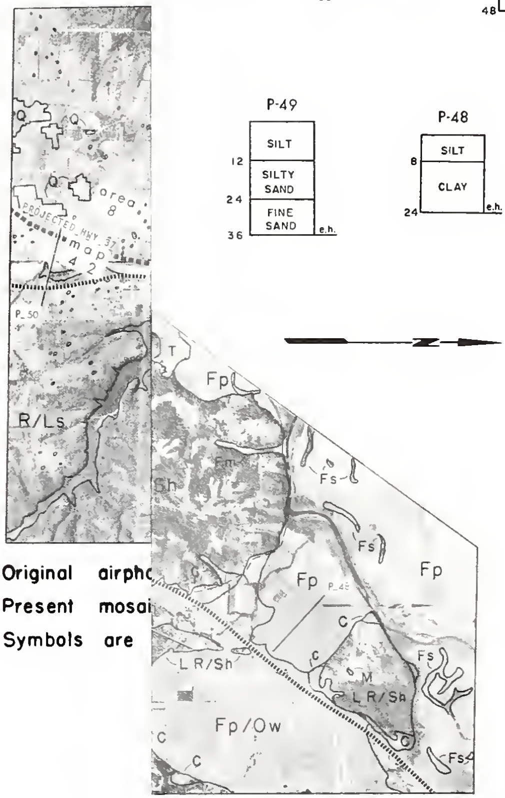
Present mosaic scale 1:80000

Symbols are explained on previous legend

AIRPHOTO INTERPRETATION & PHOTOGRAMMETRY LABORATORY JOINT HIGHWAY RESEARCH PROJECT SCHOOL OF CIVIL ENGINEERING PURDUE UNIVERSITY
INDIANA STATE HIGHWAY NO. 37 ENGINEERING SOILS MAP
MAP SCALE 1:80,000 SHEET NO. 2 of 19 DATE Aug. 1968
PHOTO INTERPRETATION by M.G.T. TRACED by D.L.S.
AIRPHOTOS NOS. (USDA - ASCS) of scale 1:20000 dated 62-67
FILM TYPE Pan PRINTS B & W FIELD CHECKED by M.G.T.







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PURDUE UNIVERSITY

INDIANA STATE HIGHWAY NO. 37
ENGINEERING SOILS MAP

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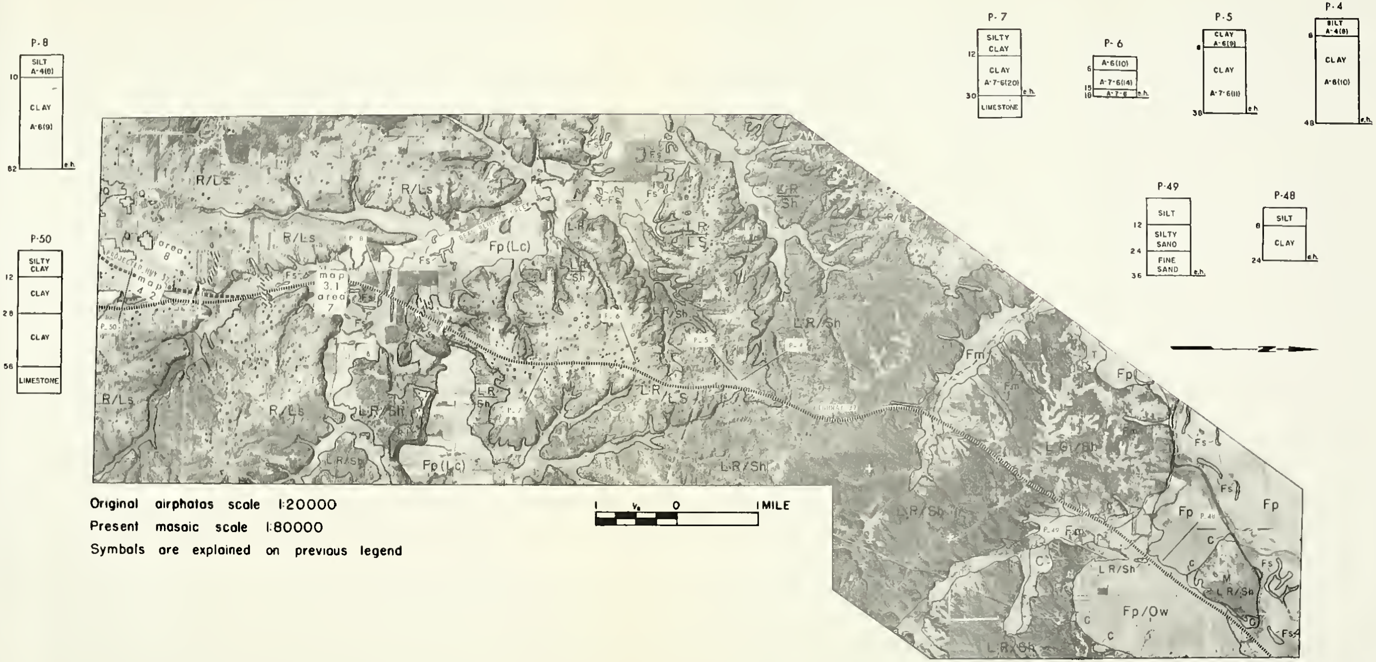

Original airphotos scale 1:20000

Present mosaic scale 1:80000

Symbols are explained on previous legend

MARTINSVILLE - BLOOMINGTON SEGMENT 3

MAP SCALE 1:80000 SHEET NO. 3 of 19 DATE AUG 1966	
PHOTO INTERPRETATION by MGT TRACED by DLS	
AIRPHOTOS NOS. (USDA-ASCS) of scale 1:20000 dated 62-67	
FILM TYPE Pan PRINTS B&W FIELD CHECKED by MGT	

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PURDUE UNIVERSITY

INDIANA STATE HIGHWAY NO. 37

ENGINEERING SOILS MAP

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SCHOOL OF CIVIL ENGINEERING
PURDUE UNIVERSITY

INDIANA STATE HIGHWAY NO. 37

ENGINEERING SOILS MAP

MAP SCALE 1:80000 SHEET NO. 4 of 19 DATE AUG. 1968
PHOTO INTERPRETATION by M.G.T. TRACED by DLS
AIRPHOTOS NOS. (USDA ASCS) at scale 1:20000 dated 62-67
FILM TYPE Pan. PRINTS B&W FIELD CHECKED by M.G.T.

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Symbols are explained on previous legend

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BLOOMINGTON - MONROE RESERVOIR SEGMENT 4

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JOINT HIGHWAY RESEARCH PROJECT
SCHOOL OF CIVIL ENGINEERING
PURDUE UNIVERSITY

INDIANA STATE HIGHWAY NO. 37

ENGINEERING SOILS MAP

MAP SCALE 1:80000 SHEET NO. 4 of 19 DATE AUG. 1968
PHOTO INTERPRETATION by M.G.T. TRACED by DLS
AIRPHOTOS NOS. (USDA) (ASCS) of scale 1:20000 dated '62-'67
FILM TYPE Pan. PRINTS B&W FIELD CHECKED by M.G.T.

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INDIANA STATE HIGHWAY NO. 37

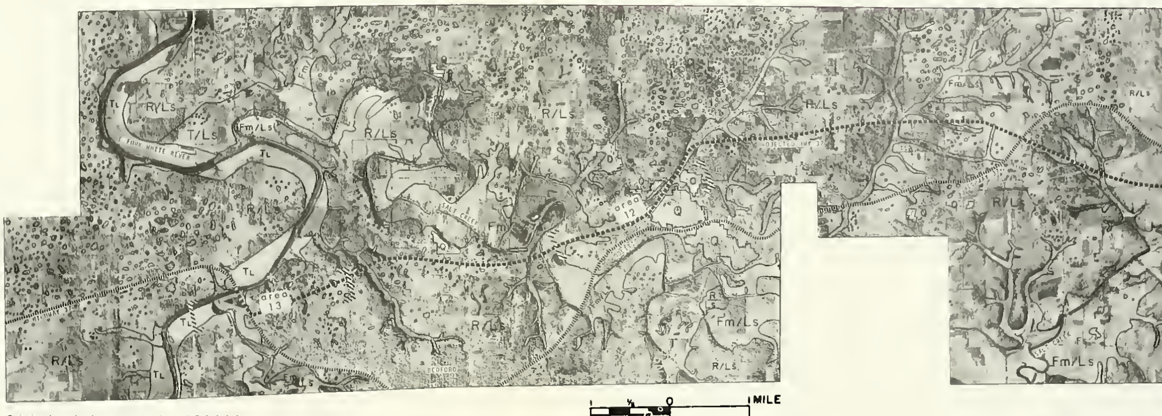
ENGINEERING SOILS MAP

MAP SCALE 1:80000 SHEET NO. 5 of 19 DATE AUG. 1968

PHOTO INTERPRETATION by MGT TRACED by DLS

AIRPHOTOS NOS. (USDA ASCS) of scale 1:20000 dated '62-67

FILM TYPE Pan. PRINTS B&W FIELD CHECKED by M.G.T.



Original airphotos scale 1:20000
Present mosaic scale 1:80000
Symbols are explained on previous legend

AIRPHOTO INTERPRETATION & PHOTOGRAMMETRY LABORATORY
JOINT HIGHWAY RESEARCH PROJECT
SCHOOL OF CIVIL ENGINEERING
PURDUE UNIVERSITY

INDIANA STATE HIGHWAY NO. 37

ENGINEERING SOILS MAP

MAP SCALE 1:80000 SHEET NO. 8 of 19 DATE AUG 1968
PHOTO INTERPRETATION by M.G.T. TRACED by D.L.S.
AIRPHOTOS NOS. (USDA ASCS) at scale 1:20000 dated '62-67
FILM TYPE Pan. PRINTS B&W FIELD CHECKED by M.G.T.

OOLITIC - BEDFORD SEGMENT 5

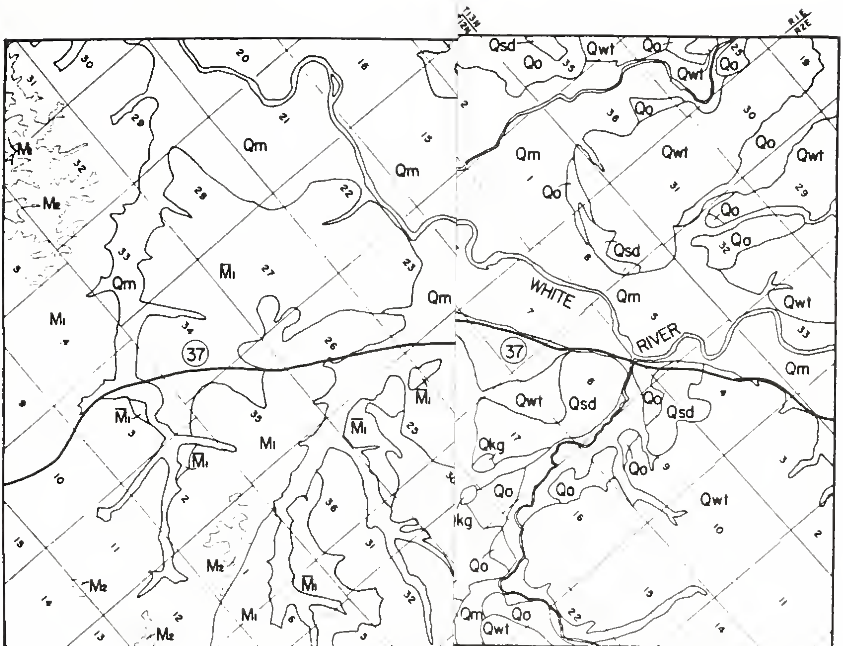
The symbols used on the photo-maps and on other maps are explained on Figure 32. The symbols used are modifications of symbols suggested by Lueder [147]. The symbols are divided into five different parts to indicate successively the land form, the soil textural class, the drainage class, the depth to bedrock class and the slope class. Examples are given on the legend sheet shown in Figure 32.

The general land form-parent material maps (photo-maps 1 to 5) were developed to provide a regional concept of physiography and materials distribution over the area of study. This kind of general map is necessary to assist in the preparation of detailed large scale engineering soil maps. The symbols used are similar from one map to the other for the whole project. The regional map is required unless county engineering soil maps are available.

3.22 Engineering Soil Mapping from Geological Data

A set of 7.5 minute quadrangle geological field sheets were made available to the author [88] and used to prepare Figure 33. These sheets were not final nor were they ready for publication, but they contained the detailed information that was required. Figure 33 indicates the very broad textural classes of materials. This is explained by the fact that the surficial geology is mapped according to Pleistocene formations.

As described by Wayne [252], Pleistocene sediments are classified into separate units on the basis of (1) lithologic characteristics and (2) distinctive marker beds at major unconformities. In this manner, glacial sediments of Pleistocene age are mapped according to standard stratigraphic practice as for rock units. Mappable units are also correlated with time-stratigraphic units recognized in Pleistocene geology



Reference Field Sheets (7 ½-minute), Indiana Geological Survey

QUATERNARY

Qm MARTINSVILLE FORMATION glacier deposits

modern alluvial deposits of stream c me thin layers

and flood plains, mostly sand and s

Qp PROSPECT FORMATION

older alluvial deposits of low terrac NE

silt and clay.

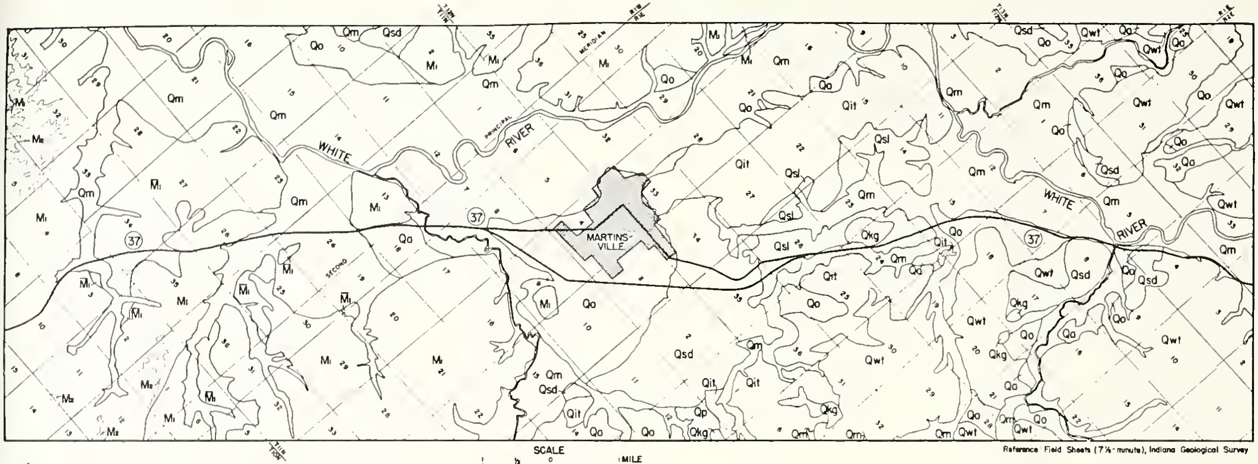
Qsd,Ql ATHERTON FORMATION siltstone)

dunes and loess facies; eolian depo entiated glacial

sand and of loess. Qsl, combination

and loess.

FI(



QUATERNARY

Qm	MARTINSVILLE FORMATION modern alluvial deposits of stream channels and flood plains, mostly sand and silt.
Qp	PROSPECT FORMATION older alluvial deposits of low terraces, mostly silt and clay.
Qsd,Ql	ATHERTON FORMATION dunes and loess facies; eolian deposits of sand and of loess. Qsl, combination of sand and loess.
Qo	ATHERTON FORMATION outwash facies; glacio-fluvial deposits of valley trains and outwash plains, mostly sand and gravel.
Qkg	TRAFALGAR FORMATION kame facies ice-contact deposits of kames and eskers, mostly gravel and sand.
Qwt	TRAFALGAR FORMATION younger glacier deposits of till plains and end moraines, mostly till, some thin layers of stratified drift.
Qit	JESSUP FORMATION older glacier deposits of till plains, mostly till, some thin layers of stratified drift.

UNCONFORMITY

MISSISSIPPIAN

M_2	HARRODSBURG LIMESTONE
M_1	BORDEN GROUP (mainly siltstone)
$\overline{M_1}$	siltstone covered by undifferentiated glacial drift and residual soils.

FIGURE 33 ENGINEERING SOIL MAP FROM GEOLOGICAL DATA

and in conformity with established stratigraphic practice. Geomorphology is recognized as an invaluable aid in determining continuity and areal extent of each unit. Biostratigraphic data in conjunction with other stratigraphic information are also used by Wayne. The result is a very coherent classification of Pleistocene units on the basis of lithography, texture and composition.

After close examination of Figure 33, the author concluded that even though Wayne's classification is more logical and useful than previous Pleistocene mapping done on the sole basis of geomorphology, it results in only very broad classes of materials and cannot be sufficient for engineering soil mapping. It is concluded that a geologic map, even a geologic map on the basis of textural classes of the glacial sediments, is not sufficient for engineering soils mapping.

To document this point, it must be indicated that the bedrock areas on Figure 33 show the symbol for the rock formation alone and nothing is indicated about the soil cover. This is a major lack of information that cannot be corrected when using geological data alone. Moreover, the geologic maps neglect the subdivisions of minor land forms and cannot be divided into discrete areas for which refined textural symbols apply (compare Figure 33 to Figure 37 and to photo-maps 2.2 and 2.3 on subsequent pages).

3.23 Engineering Soil Mapping from Pedological Data.

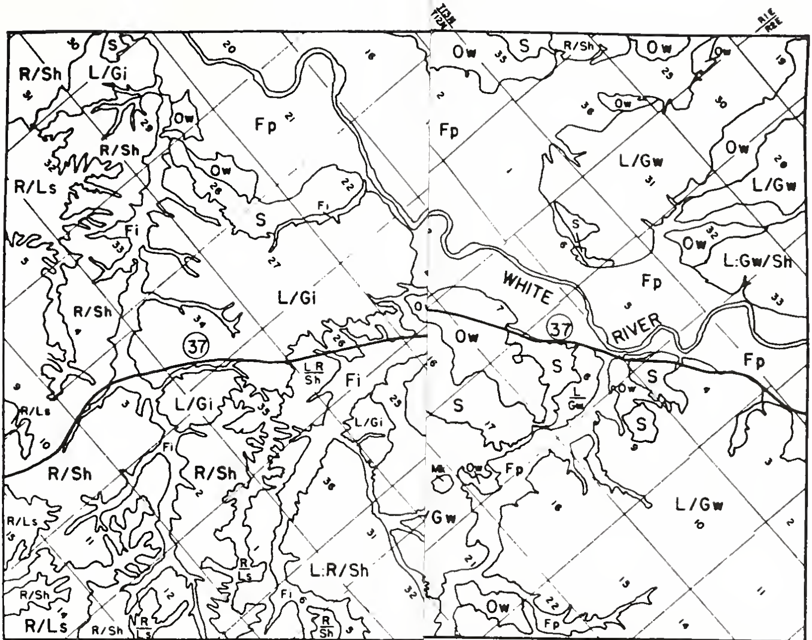
An attempt was made to prepare an engineering soil map from pedological data exclusively, for the same area around Martinsville, as in Figure 33. For this purpose, the agricultural soil map by Ulrich et al. [249] was used.

A legend was developed in which the soil series were related to a land form as given in the soils report. This resulted in a map as shown in Figure 34.

In an attempt to go further and subdivide the pedological information into textural classes and other engineering information of significance such as drainage and local relief, the symbols developed for the land form classification had to be extended. Two principal references were used: the book on engineering characteristics of soils for Indiana (Bulletin 87) [27] and the report on a regional approach to highway soils considerations by Lovell and Sisiliano [142]. The first report was used for the textural classes and the second for the drainage classes and slope classes. The two detailed engineering soils maps are shown in Figures 35 and 36. On these maps, the soils boundaries are those of the pedological map. The symbols used can be divided into four components: the land form, the soil textural class (or classes), the drainage class and the slope class. No information could be obtained from the pedological data that could lead to an inferred class to indicate depth to bedrock.

These maps obtained from pedological data are accurate in terms of broad classes of materials, when compared to the photo-maps for the same areas. No field check was made to any great extent previous to their completion. Field checking was done only for the photo-maps.

The engineering soils maps prepared from pedological data are fine for small scale maps (of the order of $\frac{1}{2}$ mi. to 1 inch) but cannot be enlarged and interpreted to yield reliable large scale engineering soil maps. But large scale aerial photos can yield such information upon interpretation.



ural Soils Maps Morgan and Monroe Counties]
well C.W.Jr., Sisiliono W.J., 1967]

Fp	Flood plain and major drain‹oils on shale and

(Includes soil series: Eel, Gennes clays, some high clays

Shoals.) { Silt and silty clays, some fine sands, minor organic Velston, Zanesville.)

Fi	Flood plain and major drainaale and siltstone

(Atkins, Haymond, Philo, Pope, St and silty

Wakeland, Wilbur.) { Silts, some fine minor sands and

S	Sand dunes imestone

(Ayrshire, Princeton, Ragsdale.) .) { Silts, clays and high plasticity clays

Ow	Outwash and valley-train deposiNG SOIL MAP FROM

(Abington, Fox, Mahalasville, Mart

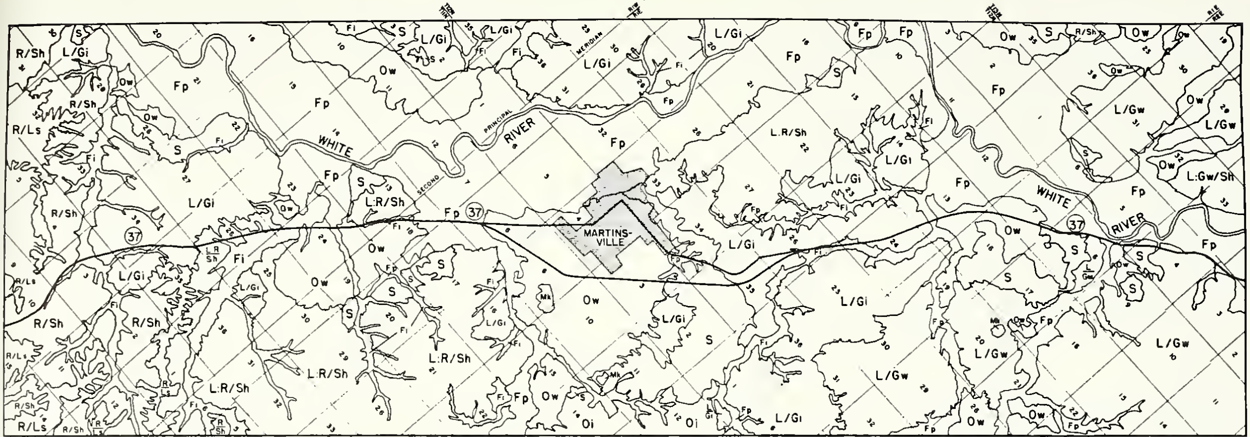
Whitaker.) { Silty clays over sands and gravels

A legend was developed in which the soil series were related to a land form as given in the soils report. This resulted in a map as shown in Figure 34.

In an attempt to go further and subdivide the pedological information into textural classes and other engineering information of significance such as drainage and local relief, the symbols developed for the land form classification had to be extended. Two principal references were used: the book on engineering characteristics of soils for Indiana (Bulletin 87) [27] and the report on a regional approach to highway soils considerations by Lovell and Sisiliano [142]. The first report was used for the textural classes and the second for the drainage classes and slope classes. The two detailed engineering soils maps are shown in Figures 35 and 36. On these maps, the soils boundaries are those of the pedological map. The symbols used can be divided into four components: the land form, the soil textural class (or classes), the drainage class and the slope class. No information could be obtained from the pedological data that could lead to an inferred class to indicate depth to bedrock.

These maps obtained from pedological data are accurate in terms of broad classes of materials, when compared to the photo-maps for the same areas. No field check was made to any great extent previous to their completion. Field checking was done only for the photo-maps.

The engineering soils maps prepared from pedological data are fine for small scale maps (of the order of $\frac{1}{2}$ mi. to 1 inch) but cannot be enlarged and interpreted to yield reliable large scale engineering soil maps. But large scale aerial photos can yield such information upon interpretation.

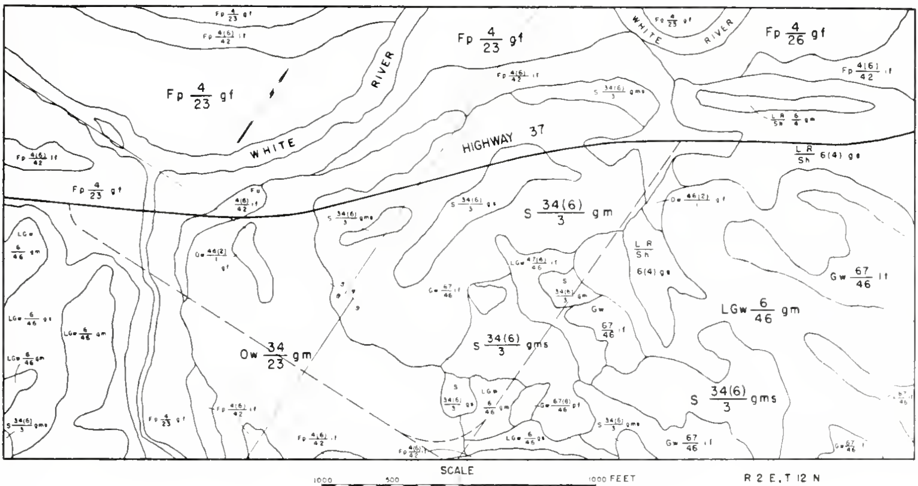


SCALE
1 ½ 0 1 MILE

References: [Agricultural Soils Maps Morgan and Monroe Counties] and [Lovell C.W Jr., Stelliano W.J., 1967]

Fp	Flood plain and major drainage ways (Includes soil series: Eel, Gennessee, Ross, Shoals.) {Silt and silty clays, some fine sands, minor organic
Fi	Flood plain and major drainage ways (Atkins, Haymond, Philo, Pope, Stendal, Wakeland, Wilbur.) {Silts, some fine sands, minor sands and gravels
S	Sand dunes (Ayrshire, Princeton, Ragsdale.) {Silts and sands
Ow	Outwash and valley-train deposits (Abington, Fox, Mahalasville, Martinsville, Whitaker.) {Silty clays over sands and gravels
Oi	Outwash and valley-train deposits (Morganstown, Taggart.) {Silty clays, minor organic over sands and gravels
Gw	Ground moraine of Wisconsin age (Bethel, Brookston, Crosby, Delmar, Fincastle, Miami, Washtenaw) {Clays and silty clays some organic, minor sands and gravels
L/Gw	Loess on ground moraine (Wisconsin) (Gregg, Plano, Russel.) {Silts and clays over Gw
L/Gi	Loess on ground moraine (Illinois) (Avonburg, Bartle, Cincinnati, Elkinsville, Grayford, Parke, Pekin, Peoga, Vigo.) {Clays, silty clays, silts, minor high plasticity clays, minor sands
L:R/Sh	Loess or residual soils on shale and siltstone {Silt, silty clays, some high plasticity clays (Muskingum, Tilsit, Welston, Zanesville.)
R/Sh	Residual soil on shale and siltstone (Muskingum.) {Silts and silty clays
R/Ls	Residual soils on limestone (Bedford, Frederick.) {Silts, clays and high plasticity clays

FIGURE 34 ENGINEERING SOIL MAP FROM PEDOLOGICAL DATA



LANDFORM CLASSIFICATION

Fp	Flood plain and major drainage ways
S	Sand dunes and silt mounds
Ow	Outwash and valley-train deposits
Gw	Ground moraine of Wisconsin age
LGw	Loess on ground moraine (Wisconsin)
L R/Sh	Loess on residual soils over siltstone and shale

DRAINAGE CLASSIFICATION

p	poor
i	imperfect
g	good

SLOPE CLASSIFICATION

f	flat
m	moderate
s	steep

TEXTURE CLASSIFICATION

1 Sands and gravels
2 Silty to clayey sands and gravels
3 Fine sands
4 Silty soils
5 Silty elastic soils
6 Clays
7 Clays (high plasticity)
8 Organic

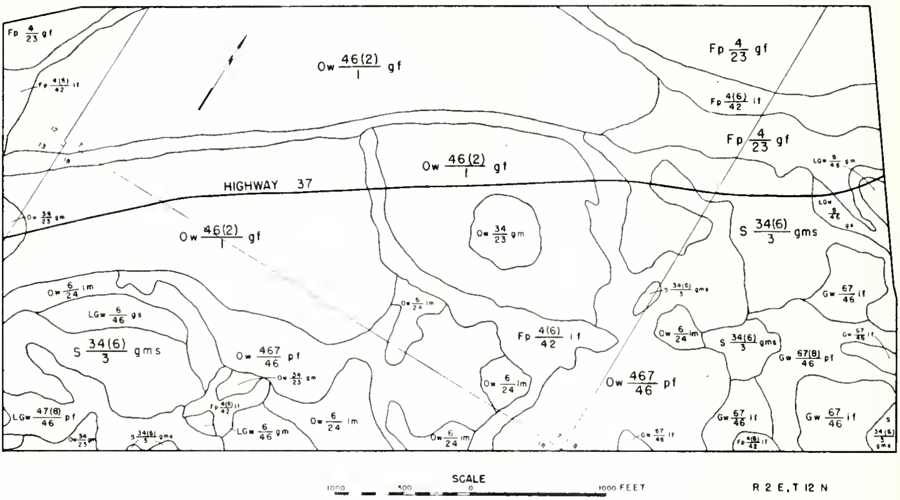
Example $\frac{67(8)}{42}$

67(8) mixture of lean clays and highly plastic clays in the A and B horizons with minor amounts of organic material

OVER

42 silt and silty to clayey sands and gravels

FIGURE 35 DETAILED ENGINEERING SOIL MAP FROM PEDOLOGICAL DATA



LANDFORM CLASSIFICATION

Fp	Flood plain and major drainage ways
S	Sand dunes and silt mounds
Ow	Outwash and valley-train deposits
Gw	Ground moraine of Wisconsin age
LGw	Loess on ground moraine (Wisconsin)
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DRAINAGE CLASSIFICATION

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f	flat
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1 Sands and gravels
2 Silty to clayey sands and gravels
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5 Silty elastic soils
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7 Clays (high plasticity)
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Example $\frac{67(8)}{42}$

67(8) mixture of lean clays and highly plastic clays in the A and B horizons with minor amounts of organic material

OVER

42 silt and silty to clayey sands and gravels

FIGURE 36 DETAILED ENGINEERING SOIL MAP FROM PEDOLOGICAL DATA

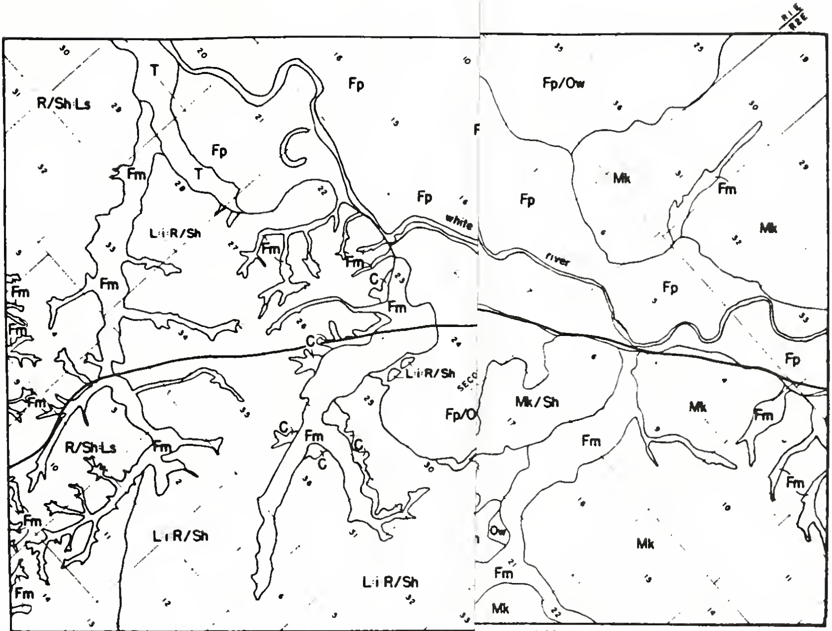
3.24 Engineering Soil Maps from Black and White Airphotos

Figure 37 illustrates the engineering soil map obtained from black and white aerial photographs in order to compare the result with what was obtained from the geological and pedological information. The overall compatibility of these maps is most striking.

This terminates the comparison between geological, pedological and aerial photographic data as a source for mapping engineering soils. It is concluded that detailed geological maps are useful but not sufficient to map engineering soils. It is also concluded that pedological maps can greatly contribute to engineering soils mapping but they are limited in terms of indicating precise locations of soil boundaries and in terms of giving information on the environment and on the prevailing soil conditions.

Several other engineering soils maps were prepared and reproduced as photo-maps in order to compare the gain of information obtained from the different types of aerial films and prints. The photo-maps prepared from black and white airphotos are reproduced as photo-maps 1.1 to 4.1 (Plates 6 to 11). Table 4 was prepared for an easier identification of the maps produced in this report and as a convenient listing of source of information, scale and numbering.

The photo-maps on Plates 6 to 11 and on Plates 12 to 14 are examples of the accrued details reported on the map, as the photo scale increases (from small scale, 1:20,000 to large scale 1:4,800). They show also that the amount of detail is not only a function of the photo scale but is primarily related to the environment and terrain (see Plates 6,7 and 8).



erence : USDA - ASCS Aerial photographs 1962-1967

Fp Floodplain and major drainage nd Dunes on Wisconsin Ridge

Sands and silts, some clays, minor course sands and d sands over mixed silts and clays with minor sands

Fm Minor drainage ways erlying Residual soil derived

Silts, sands and clays edrock at Shallow depth

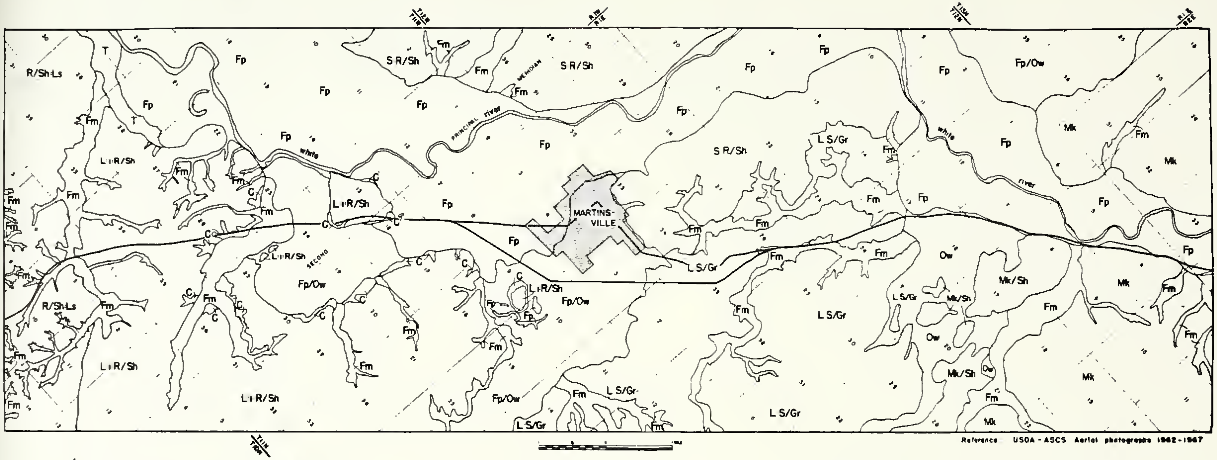
C Colluvial deposits linoian Till over Residual

Silts and fine sands minor clays from Shale bedrock

T Terrace derived from Shale and

Sands and gravels some silts and minor clays rock Clays, high plasticity clays and silts over bedrock

FIGURE N



Fp	Floodplain and major drainage ways — Sands and silts, some clays, minor coarse sands and gravels
Fm	Minor drainage ways — Silts, sands and clays
C	Colluvial deposits — Silts and fine sands minor clays
T	Terrace — Sands and gravels some silts and minor clays
Ow	Outwash and Valley-train deposits — Sands and gravel some silts and clays
Fp/Ow	Reworked Outwash — Silts, clays and sands over sands and gravels
Mk	Kame Moraine of Wisconsin Age — Sands and gravels
Mk/Sh	Kame Moraine over Shale bedrock at shallow depth — Silts, sands and gravels over Shale and siltstone
L:S/Gr	Loess and Sand Dunes on Wisconsin Ridge Moraine
S:R/Sh	Sand Dunes overlying Residual soil derived from Shale bedrock at Shallow depth
L:I:R/Sh	Loess over Illinoian Till over Residual Soils derived from Shale bedrock
R/Sh-Ls	Residual soils derived from Shale and Limestone bedrock — Clays, high plasticity clays and silts

FIGURE 37 ENGINEERING SOIL MAP FROM AIRPHOTO–INTERPRETATION

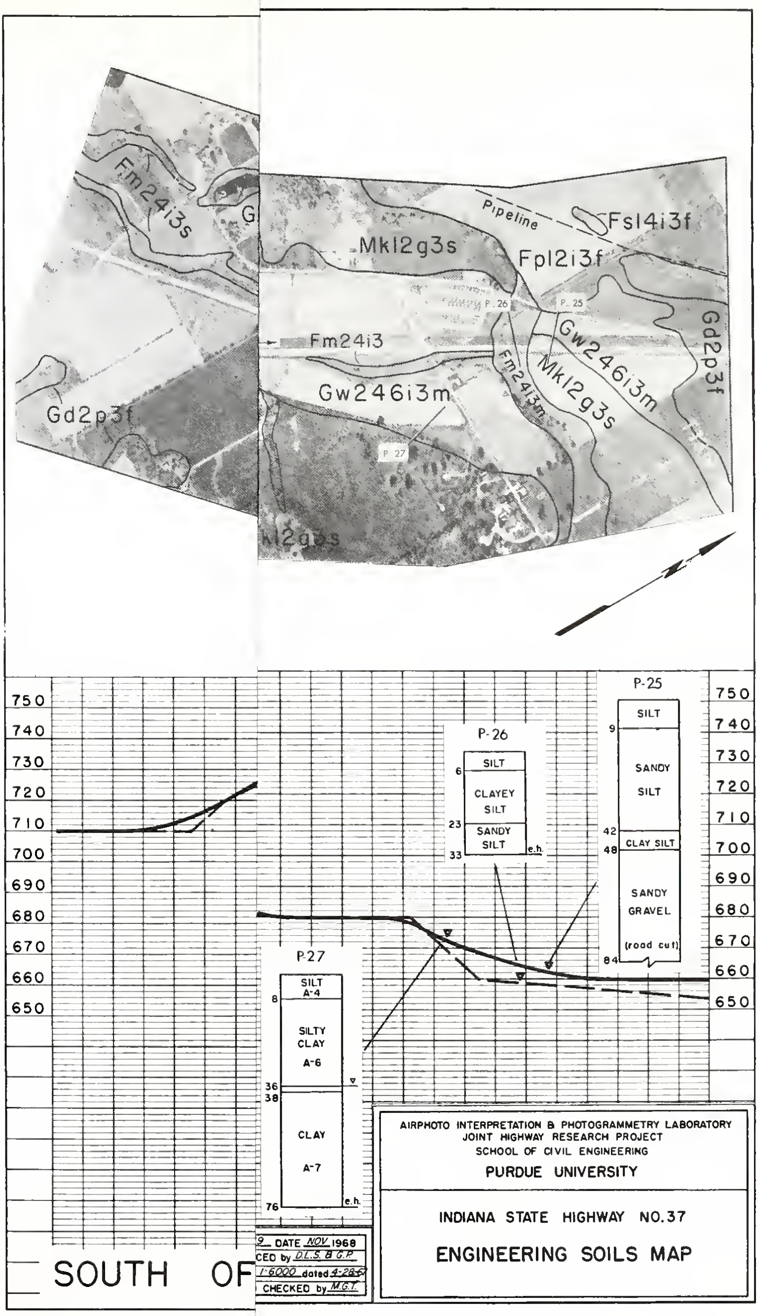
TABLE 4

LIST OF ENGINEERING SOIL MAPS GENERATED IN THE INDIANA S.R. 37 STUDY

Map Title	Source	Scale	Figure or Map Plate No.
SOUTH OF INDIANAPOLIS SEGMENT 1	1:20,000 BW airphotos	1:20,000 (1:80,000)	Photo-Map 1 (Plate 1)
MARTINSVILLE SEGMENT 2	1:20,000 BW airphotos	1:20,000 (1:80,000)	Photo-Map 2 (Plate 2)
MARTINSVILLE-BLOOMINGTON SEGMENT 3	1:20,000 BW airphotos	1:20,000 (1:80,000)	Photo-Map 3 (Plate 3)
BLOOMINGTON-MONROE RESERVOIR SEGMENT 4	1:20,000 BW airphotos	1:20,000 (1:80,000)	Photo-Map 4 (Plate 4)
OOLITIC-BEDFORD SEGMENT 5	1:20,000 BW airphotos	1:20,000 (1:80,000)	Photo-Map 5 (Plate 5)
ENGINEERING SOIL MAP FROM GEOLOGICAL DATA	7.5 Min. Quad. Geological Maps	1:24,000 (1:84,480)	Figure 33
ENGINEERING SOIL MAP FROM PEDOLOGICAL DATA	7.5 Min. Quad. Pedological Map	1:24,000 (1:84,480)	Figure 34
DETAILED ENGINEERING SOIL MAPS FROM PEDOLOGICAL DATA	Pedological Map and Engineering-Pedological Soils References	1:24,000 (1:13,000)	Figures 35 and 36
ENGINEERING SOIL MAP FROM AIRPHOTO-INTERPRETATION	BW aerial photographs	1:20,000 (1:84,480)	Figure 37
SOUTH OF INDIANAPOLIS SEGMENT 1.1	1:4,800 BW airphotos	1:6,000 (1:15,000)	Photo-Map 1.1 (Plate 6)
MARTINSVILLE SEGMENT 2.1	1:4,800 BW airphotos	1:6,000 (1:15,000)	Photo-Map 2.1 (Plate 7)

TABLE 4 (Continued)

Map Title	Source	Scale	Figure or Map Plate No.
MARTINSVILLE SEGMENT 2.2	1:4,800 BW airphotos	1:6,000 (1:15,000)	Photo-Map 2.2 (Plate 8)
MARTINSVILLE SEGMENT 2.3	1:4,800 BW airphotos	1:6,000 (1:15,000)	Photo-Map 2.3 (Plate 9)
MARTINSVILLE-BLOOMINGTON SEGMENT 3.1	1:4,800 BW airphotos	1:6,000 (1:15,000)	Photo-Map 3.1 (Plate 10)
BLOOMINGTON-MONROE RESERVOIR SEGMENT 4.1	1:4,800 BW airphotos	1:6,000 (1:15,000)	Photo-Map 4.1 (Plate 11)
MARTINSVILLE SEGMENT 2.2.1	1:4,800 BW airphotos	1:6,000 (1:6,000)	Photo-Map 2.2.1 (Plate 12)
MARTINSVILLE SEGMENT 2.2.2	1:4,800 BW airphotos	1:6,000 (1:6,000)	Photo-Map 2.2.2 (Plate 13)
MARTINSVILLE SEGMENT 2.3.1	1:4,800 BW airphotos	1:6,000 (1:6,000)	Photo-Map 2.3.1 (Plate 14)
MARTINSVILLE SEGMENT 2.3(C)	1:4,800 Color prints	1:6,000 (1:15,000)	Photo-Map 2.3(C) (Plate 15)
MARTINSVILLE-BLOOMINGTON SEGMENT 3.1(C)	1:4,800 Color prints	1:6,000 (1:15,000)	Photo-Map 3.1(C) (Plate 16)
BLOOMINGTON-MONROE RESERVOIR SEGMENT 4.1(C)	1:4,800 Color prints	1:6,000 (1:15,000)	Photo-Map 4.1(C) (Plate 17)
MARTINSVILLE SEGMENT 2.2.1(C)	1:4,800 Color prints	1:6,000 (1:6,000)	Photo-Map 2.2.1(C) (Plate 18)
MARTINSVILLE SEGMENT 2.2.2(C)	1:4,800 Color prints	1:6,000 (1:6,000)	Photo-Map 2.2.2(C) (Plate 19)



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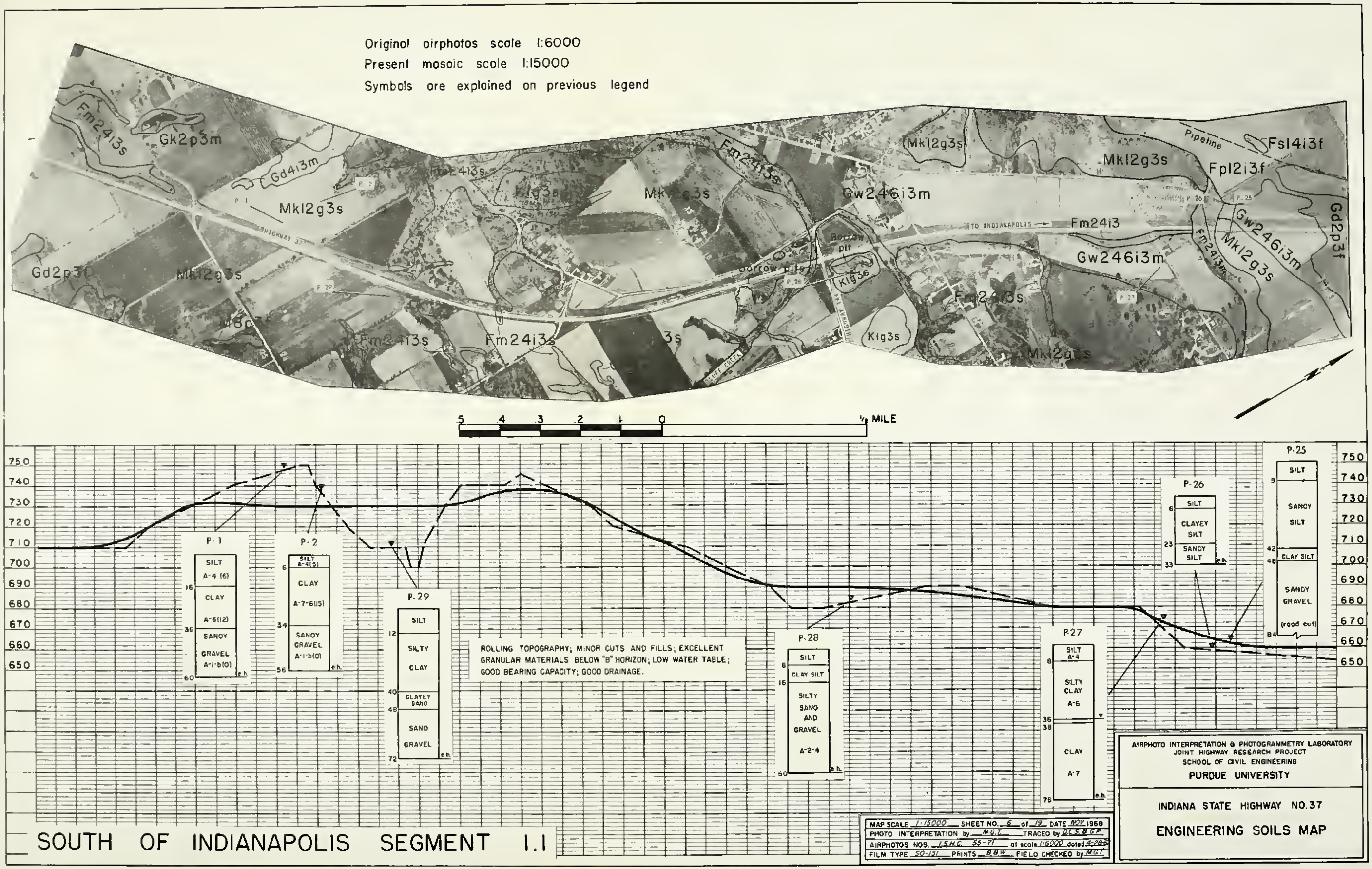
Mkl2g3s
Pipeline
Fsl4i3f
Fpl2i3f
P-26
P-25
Fm24i3
Gd2p3f
Gw246i3m
Fm24i3m
Mkl2g3s
Gw246i3m
Gd2p3f
P 27
kl2g3s
750
740
730
720
710
700
690
680
670
660
650
P-25
SILT
9
SANDY SILT
42
48
CLAY SILT
SANDY GRAVEL
(road cut)
84
P-26
SILT
6
CLAYEY SILT
23
SANDY SILT
33
e.h.
P-27
SILT A-4
8
SILTY CLAY A-6
36
38
CLAY A-7
76
e.h.
AIRPHOTO INTERPRETATION & PHOTOGRAMMETRY LABORATORY
JOINT HIGHWAY RESEARCH PROJECT
SCHOOL OF CIVIL ENGINEERING
PURDUE UNIVERSITY
INDIANA STATE HIGHWAY NO. 37
ENGINEERING SOILS MAP
9 DATE NOV 1968
CED by D.L.S. & G.P.
1:6000 dated 4-28-67
CHECKED by M.G.T.
SOUTH OF

TABLE 4 (Continued)

Map Title	Source	Scale	Figure or Map Plate No.
MARTINSVILLE SEGMENT 2.2	1:4,800 BW airphotos	1:6,000 (1:15,000)	Photo-Map 2.2 (Plate 8)
MARTINSVILLE SEGMENT 2.3	1:4,800 BW airphotos	1:6,000 (1:15,000)	Photo-Map 2.3 (Plate 9)
MARTINSVILLE-BLOOMINGTON SEGMENT 3.1	1:4,800 BW airphotos	1:6,000 (1:15,000)	Photo-Map 3.1 (Plate 10)
BLOOMINGTON-MONROE RESERVOIR SEGMENT 4.1	1:4,800 BW airphotos	1:6,000 (1:15,000)	Photo-Map 4.1 (Plate 11)
MARTINSVILLE SEGMENT 2.2.1	1:4,800 BW airphotos	1:6,000 (1:6,000)	Photo-Map 2.2.1 (Plate 12)
MARTINSVILLE SEGMENT 2.2.2	1:4,800 BW airphotos	1:6,000 (1:6,000)	Photo-Map 2.2.2 (Plate 13)
MARTINSVILLE SEGMENT 2.3.1	1:4,800 BW airphotos	1:6,000 (1:6,000)	Photo-Map 2.3.1 (Plate 14)
MARTINSVILLE SEGMENT 2.3(C)	1:4,800 Color prints	1:6,000 (1:15,000)	Photo-Map 2.3(C) (Plate 15)
MARTINSVILLE-BLOOMINGTON SEGMENT 3.1(C)	1:4,800 Color prints	1:6,000 (1:15,000)	Photo-Map 3.1(C) (Plate 16)
BLOOMINGTON-MONROE RESERVOIR SEGMENT 4.1(C)	1:4,800 Color prints	1:6,000 (1:15,000)	Photo-Map 4.1(C) (Plate 17)
MARTINSVILLE SEGMENT 2.2.1(C)	1:4,800 Color prints	1:6,000 (1:6,000)	Photo-Map 2.2.1(C) (Plate 18)
MARTINSVILLE SEGMENT 2.2.2(C)	1:4,800 Color prints	1:6,000 (1:6,000)	Photo-Map 2.2.2(C) (Plate 19)



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Present mosaic scale 1:15000
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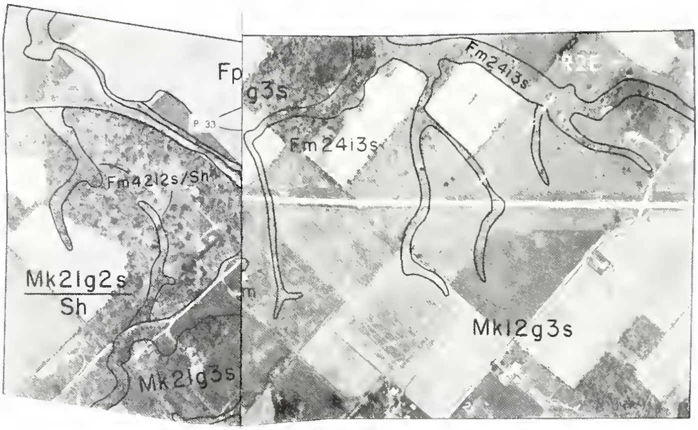
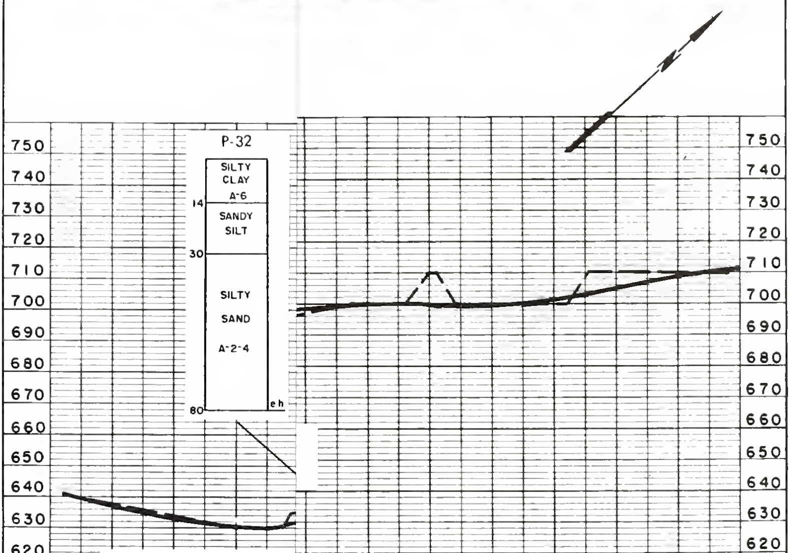
Fm24i3
Gw246i3m
Kig3s
Mkl2g3s
Fpl2i3f
Fsl4i3f
Gd2p3f
Pipeline
Borrow pits
Borrow pit
TO INDIANAPOLIS
HIGHWAY 37
.5 .4 .3 .2 .1 0 1/2 MILE
P-1
SILT A-4 (6)
CLAY A-6(12)
SANDY GRAVEL A-1-b(0)
P-2
SILT A-4(5)
CLAY A-7-6(15)
SANDY GRAVEL A-1-b(0)
P-29
SILT
SILTY CLAY
CLAYEY SAND
SAND GRAVEL
ROLLING TOPOGRAPHY; MINOR CUTS AND FILLS; EXCELLENT GRANULAR MATERIALS BELOW "B" HORIZON; LOW WATER TABLE; GOOD BEARING CAPACITY; GOOD DRAINAGE.
P-28
SILT
CLAY SILT
SILTY SAND AND GRAVEL A-2-4
P-27
SILT A-4
SILTY CLAY A-6
CLAY A-7
P-26
SILT
CLAYEY SILT
SANDY SILT
P-25
SILT
SANDY SILT
CLAY SILT
SANDY GRAVEL (road cut)
SOUTH OF INDIANAPOLIS SEGMENT 1.1
MAP SCALE 1:15000 SHEET NO. 6 of 19 DATE NOV. 1956
PHOTO INTERPRETATION by M.G.T. TRACED by D.L.S. & G.P.
AIRPHOTOS NOS. I.S.H.C. 55-71 at scale 1:6000 dated 4-28-55
FILM TYPE SO-151 PRINTS B&W FIELD CHECKED by M.G.T.
AIRPHOTO INTERPRETATION & PHOTOGRAMMETRY LABORATORY
JOINT HIGHWAY RESEARCH PROJECT
SCHOOL OF CIVIL ENGINEERING
PURDUE UNIVERSITY
INDIANA STATE HIGHWAY NO. 37
ENGINEERING SOILS MAP

tos scale 1:6000

c scale 1:15000

explained on previous legend





F UNITS : SEASONAL HIG
TO FLOODING; MATERIALS
SURFACE DRAINAGE; POOI
REQUIRE CONSTRUCTION (
BASEMENT OF GRANULAR

MARTINSVILLE

OATE NOV 1966
by D.L.S. & G.P.
6000 doted 4-28-67
HECKEO by M.G.T.

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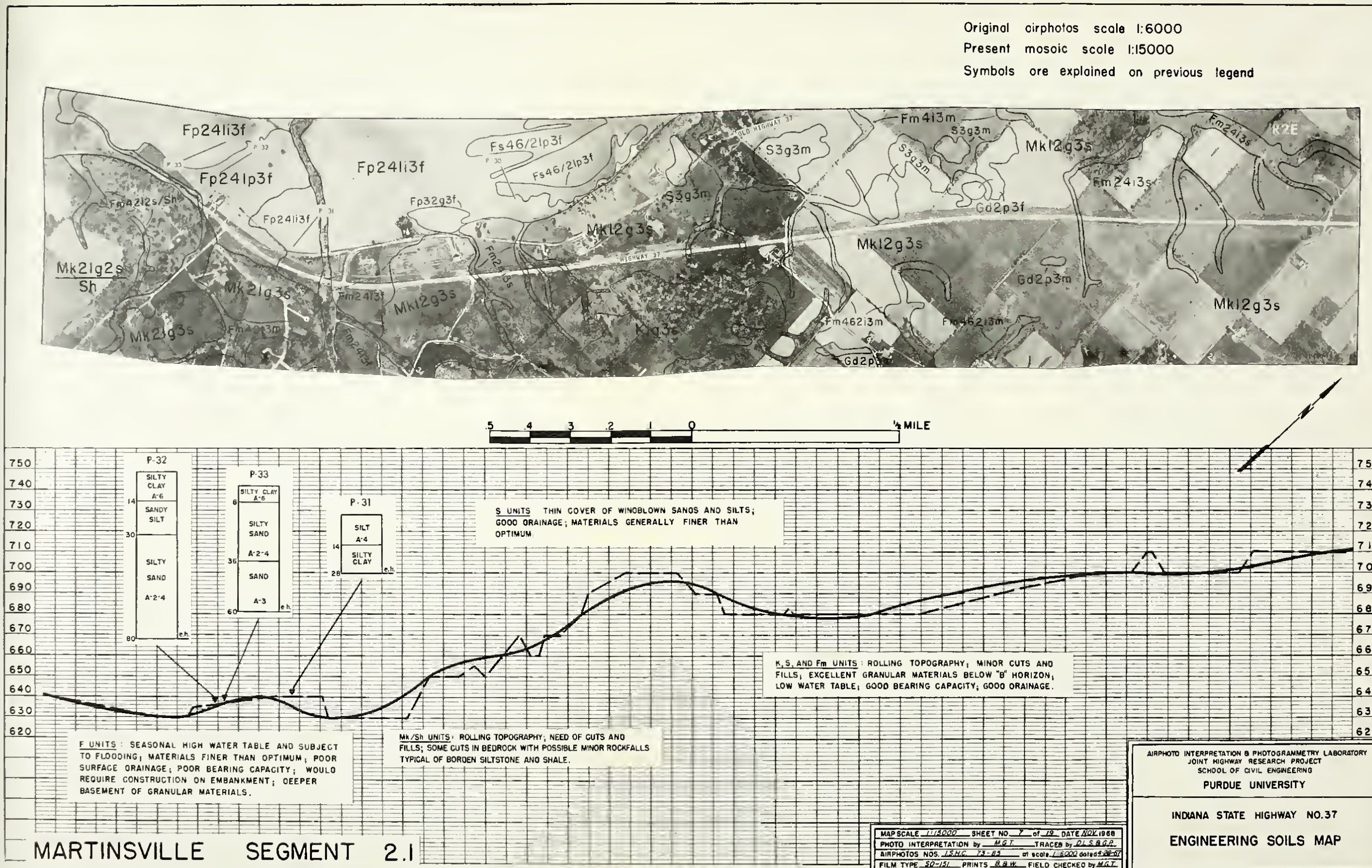
PURDUE UNIVERSITY

INDIANA STATE HIGHWAY NO.37

ENGINEERING SOILS MAP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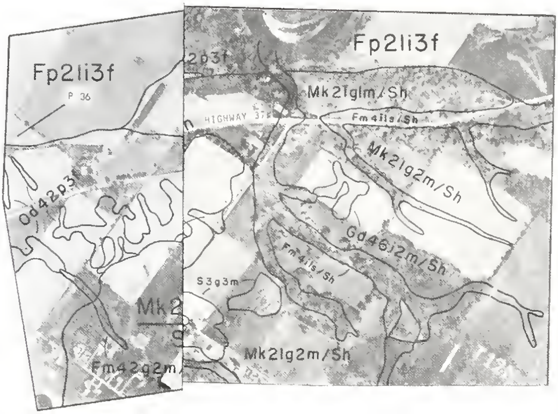
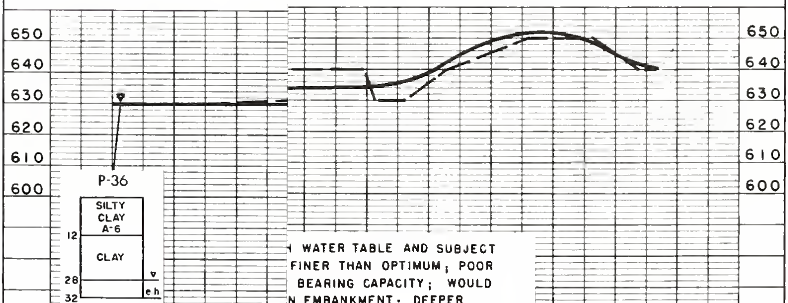
S3g3m
S3g3m
Mkl2g3s
R2E
Fm24i3s
Fm2l2s/Sh
S3g3m
Gd2p3f
Mkl2g3s
Mkl2g3s
Mk2lg2s
Sh
Mk2lg3s
Fm24i3f
Mkl2g3s
Gd2p3m
Mkl2g3s
Mk2lg3s
Fm462i3m
Fm462i3m
Gd2p3f
OLD HIGHWAY 37
HIGHWAY 37
P 31
P 32
P 33
P 30
.5 .4 .3 .2 .1 0 ½ MILE
750
740
730
720
710
700
690
680
670
660
650
640
630
620
P-32
SILTY CLAY A-6
14
SANDY SILT
30
SILTY SAND A-2-4
80
e.h.
P-33
SILTY CLAY A-6
6
SILTY SAND A-2-4
36
SAND A-3
60
e.h.
P-31
SILT A-4
14
SILTY CLAY
28
e.h.
S UNITS THIN COVER OF WINDBLOWN SANDS AND SILTS; GOOD DRAINAGE; MATERIALS GENERALLY FINER THAN OPTIMUM
K, S, AND Fm UNITS: ROLLING TOPOGRAPHY; MINOR CUTS AND FILLS; EXCELLENT GRANULAR MATERIALS BELOW "B" HORIZON; LOW WATER TABLE; GOOD BEARING CAPACITY; GOOD DRAINAGE.
F UNITS: SEASONAL HIGH WATER TABLE AND SUBJECT TO FLOODING; MATERIALS FINER THAN OPTIMUM; POOR SURFACE DRAINAGE; POOR BEARING CAPACITY; WOULD REQUIRE CONSTRUCTION ON EMBANKMENT; DEEPER BASEMENT OF GRANULAR MATERIALS.
Mk/Sh UNITS: ROLLING TOPOGRAPHY; NEED OF CUTS AND FILLS; SOME CUTS IN BEDROCK WITH POSSIBLE MINOR ROCKFALLS TYPICAL OF BORDEN SILTSTONE AND SHALE.
MARTINSVILLE SEGMENT 2.1
MAP SCALE 1:15000 SHEET NO. 7 of 19 DATE NOV 1968
PHOTO INTERPRETATION by M.G.T. TRACED by D.L.S. & G.P.
AIRPHOTOS NOS. I.S.H.C. 73-85 at scale 1:6000 dated 4-28-67
FILM TYPE SO-151 PRINTS B & W. FIELD CHECKED by M.G.T.
AIRPHOTO INTERPRETATION & PHOTOGRAMMETRY LABORATORY
JOINT HIGHWAY RESEARCH PROJECT
SCHOOL OF CIVIL ENGINEERING
PURDUE UNIVERSITY
INDIANA STATE HIGHWAY NO.37
ENGINEERING SOILS MAP

ɔhotos scale 1:6000
saic scale 1:15000
ː explained on previous legend





ı WATER TABLE AND SUBJECT
FINER THAN OPTIMUM; POOR
BEARING CAPACITY; WOULD
N EMBANKMENT; DEEPER
MATERIALS.

Mk/Sh UNITS: ROLLING
FILLS; SOME CUTS IN BEI
TYPICAL OF BORDEN SILT

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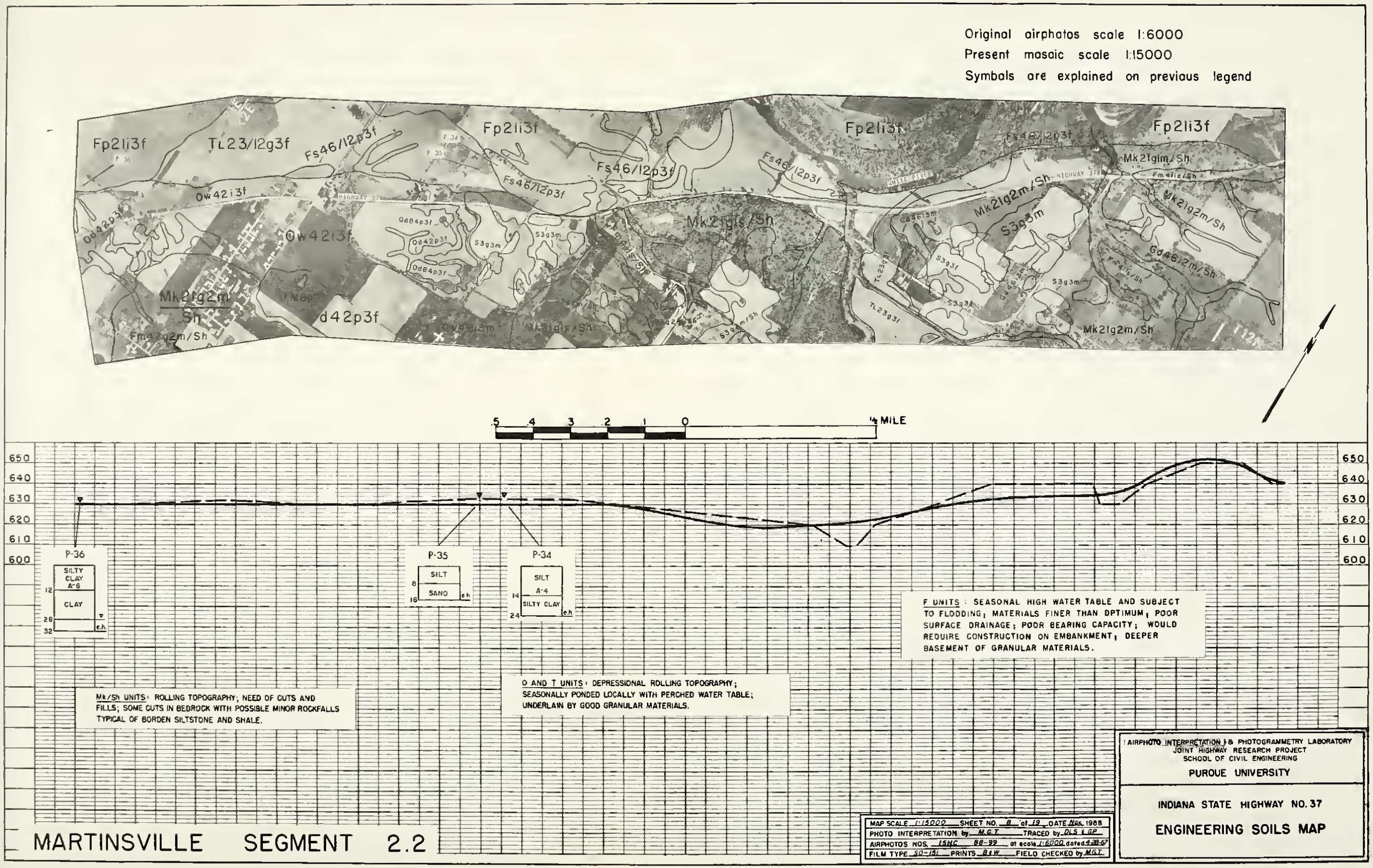
PURDUE UNIVERSITY

INDIANA STATE HIGHWAY NO. 37

ENGINEERING SOILS MAP

DATE Nov. 1968
ED by DLS & GP
6000 dated 4-28-67
CHECKED by M.G.T.

MARTINSVILL


Original airphotos scale 1:6000
Present mosaic scale 1:15000
Symbols are explained on previous legend
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Fs46/12p3f
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Od84p3f
Od42p3f
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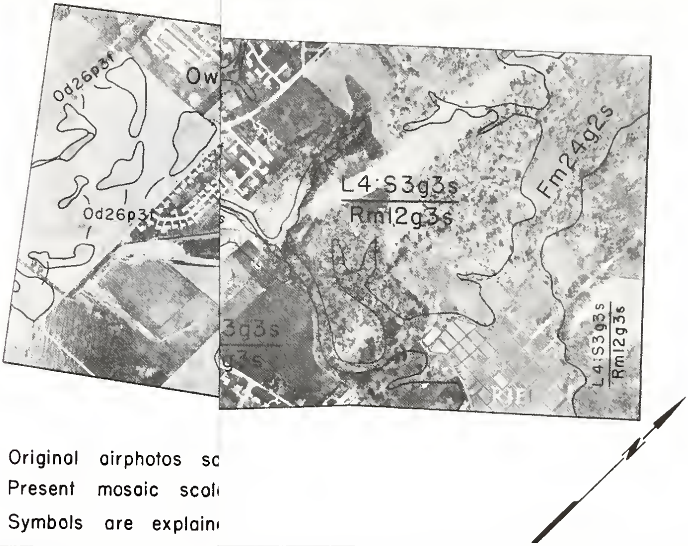
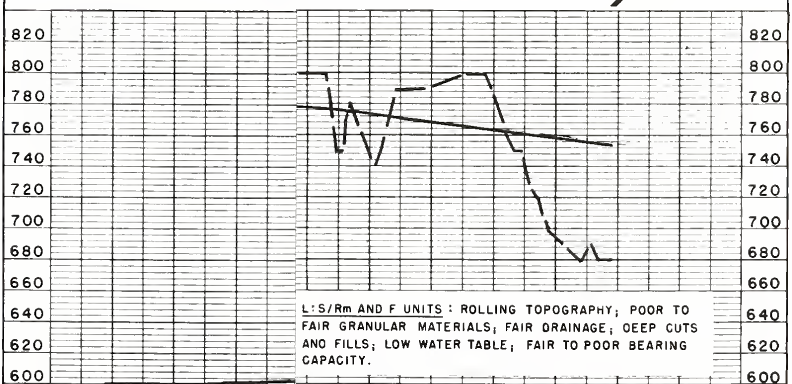
Mk2lgls/Sh
Mk2lg2m/Sh
S3g3m
Fp2li3f
Fs46/12p3f
Mk2lglm/Sh
Mk2lg2m/Sh
Gd46/2m/Sh
Mk2lg2m/Sh
Fp2li3f
TL23g3f
S3g3f
S3g3m
Mk2lg2m/Sh
d42p3f
Fm42g2m/Sh
HIGHWAY 37
WHITE RIVER
P-36
P-35
P-34
SILTY CLAY A-6
CLAY
SILT
SAND
SILT A-4
SILTY CLAY
e.h.
650
640
630
620
610
600
¼ MILE
Mk/Sh UNITS: ROLLING TOPOGRAPHY; NEED OF CUTS AND FILLS; SOME CUTS IN BEDROCK WITH POSSIBLE MINOR ROCKFALLS TYPICAL OF BORDEN SILTSTONE AND SHALE.
O AND T UNITS: DEPRESSIONAL ROLLING TOPOGRAPHY; SEASONALLY PONDED LOCALLY WITH PERCHED WATER TABLE; UNDERLAIN BY GOOD GRANULAR MATERIALS.
F UNITS: SEASONAL HIGH WATER TABLE AND SUBJECT TO FLOODING; MATERIALS FINER THAN OPTIMUM; POOR SURFACE DRAINAGE; POOR BEARING CAPACITY; WOULD REQUIRE CONSTRUCTION ON EMBANKMENT; DEEPER BASEMENT OF GRANULAR MATERIALS.
MARTINSVILLE SEGMENT 2.2
MAP SCALE 1:15000 SHEET NO. 8 of 19 DATE Nov. 1988
PHOTO INTERPRETATION by M.G.T. TRACED by DLS & GP
AIRPHOTOS NOS. 15HC 88-99 at scale 1:6000 dated 4-28-57
FILM TYPE SO-151 PRINTS B&W FIELD CHECKED by M.G.T.
AIRPHOTO INTERPRETATION & PHOTOGRAMMETRY LABORATORY
JOINT HIGHWAY RESEARCH PROJECT
SCHOOL OF CIVIL ENGINEERING
PURDUE UNIVERSITY
INDIANA STATE HIGHWAY NO. 37
ENGINEERING SOILS MAP



Original airphotos sc
Present mosaic scal
Symbols are explain



L:S/Rm AND F UNITS : ROLLING TOPOGRAPHY; POOR TO FAIR GRANULAR MATERIALS; FAIR DRAINAGE; DEEP CUTS AND FILLS; LOW WATER TABLE; FAIR TO POOR BEARING CAPACITY.

O UNITS : FLAT AND DEPRESSI
TO PONDING AND HIGH WATER
FINER THAN OPTIMUM; UNDER
MATERIALS; POOR SURFACE D

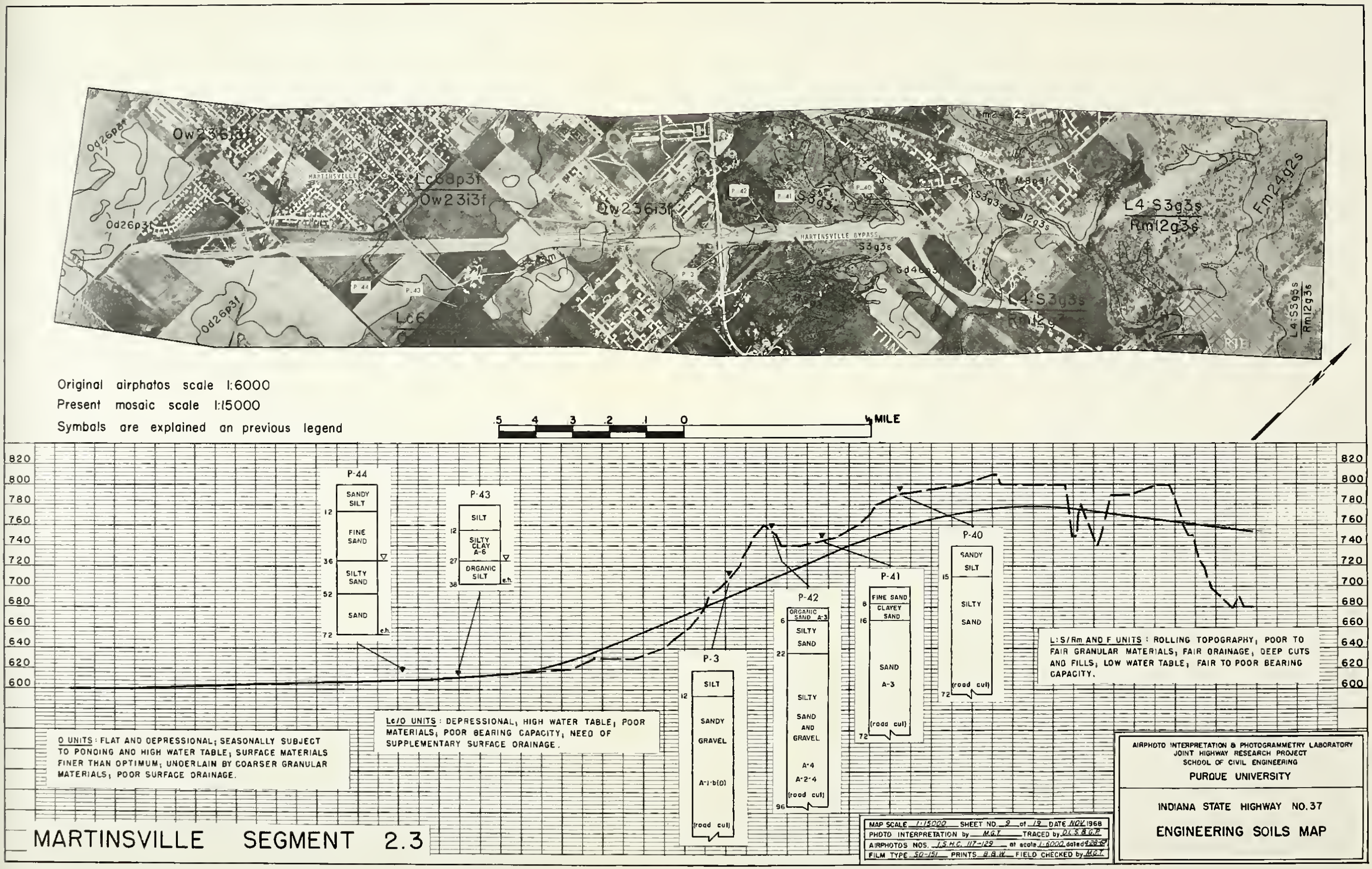
MARTINSVILL

DATE NOV 1968
D by D.L.S. & G.P.
6000 dated 4-28-67
HECKED by M.G.T.

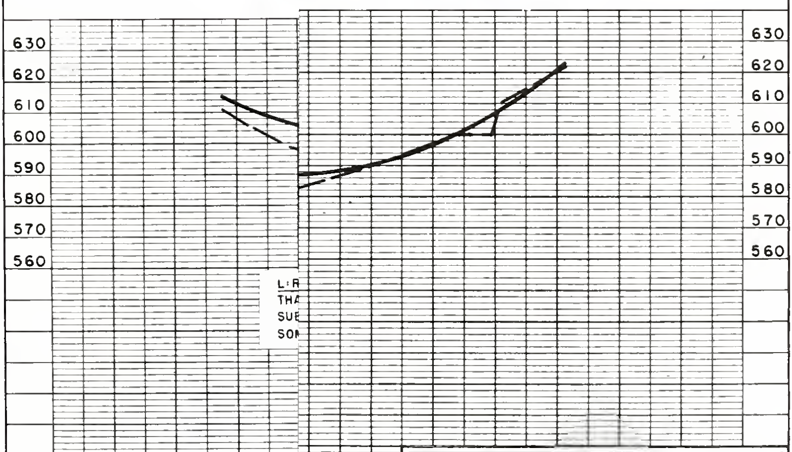
AIRPHOTO INTERPRETATION & PHOTOGRAMMETRY LABORATORY
JOINT HIGHWAY RESEARCH PROJECT
SCHOOL OF CIVIL ENGINEERING
PURDUE UNIVERSITY

INDIANA STATE HIGHWAY NO. 37

ENGINEERING SOILS MAP



Ow236i3f
Od26p3f
MARTINSVILLE
Lc68p3f
Ow23i3f
Ow236i3f
P-42
P-41
S3g3s
P-40
MARTINSVILLE BYPASS
S3g3s
L4:S3g3s
Rm12g3s
Fm24g2s
P 44
P-43
Lc6
Od26p3f
P 3
L4:S3g3s
L4:S3g3s
Rm12g36
Original airphotos scale 1:6000
Present mosaic scale 1:15000
Symbols are explained on previous legend
.5 .4 .3 .2 .1 0 ½ MILE
820
800
780
760
740
720
700
680
660
640
620
600
P-44
SANDY SILT
12
FINE SAND
36
SILTY SAND
52
SAND
72
e.h.
P-43
SILT
12
SILTY CLAY A-6
27
ORGANIC SILT
38
e.h.
P-3
SILT
12
SANDY GRAVEL
A-1-b(0)
(road cut)
P-42
6
ORGANIC SAND A-3
SILTY SAND
22
SILTY SAND AND GRAVEL
A-4
A-2-4
(road cut)
96
P-41
8
FINE SAND
CLAYEY SAND
16
SAND
A-3
(road cut)
72
P-40
SANDY SILT
15
SILTY SAND
(road cut)
72
L:S/Rm AND F UNITS: ROLLING TOPOGRAPHY, POOR TO FAIR GRANULAR MATERIALS, FAIR DRAINAGE, DEEP CUTS AND FILLS, LOW WATER TABLE, FAIR TO POOR BEARING CAPACITY.
Lc/O UNITS: DEPRESSIONAL, HIGH WATER TABLE, POOR MATERIALS, POOR BEARING CAPACITY, NEED OF SUPPLEMENTARY SURFACE DRAINAGE.
O UNITS: FLAT AND DEPRESSIONAL; SEASONALLY SUBJECT TO PONDING AND HIGH WATER TABLE; SURFACE MATERIALS FINER THAN OPTIMUM; UNDERLAIN BY COARSER GRANULAR MATERIALS; POOR SURFACE DRAINAGE.
MARTINSVILLE SEGMENT 2.3
MAP SCALE 1:15000 SHEET NO. 9 of 19 DATE NOV 1968
PHOTO INTERPRETATION by M.G.T. TRACED by D.L.S. & G.P.
AIRPHOTOS NOS. I.S.H.C. 117-129 at scale 1:6000 dated 4-28-67
FILM TYPE SO-151 PRINTS B.&W. FIELD CHECKED by M.G.T.
AIRPHOTO INTERPRETATION & PHOTOGRAMMETRY LABORATORY
JOINT HIGHWAY RESEARCH PROJECT
SCHOOL OF CIVIL ENGINEERING
PURDUE UNIVERSITY
INDIANA STATE HIGHWAY NO. 37
ENGINEERING SOILS MAP



DATE Nov. 1968
D by DLS & GP
5000 dated 4-28-67
CHECKED by MGT

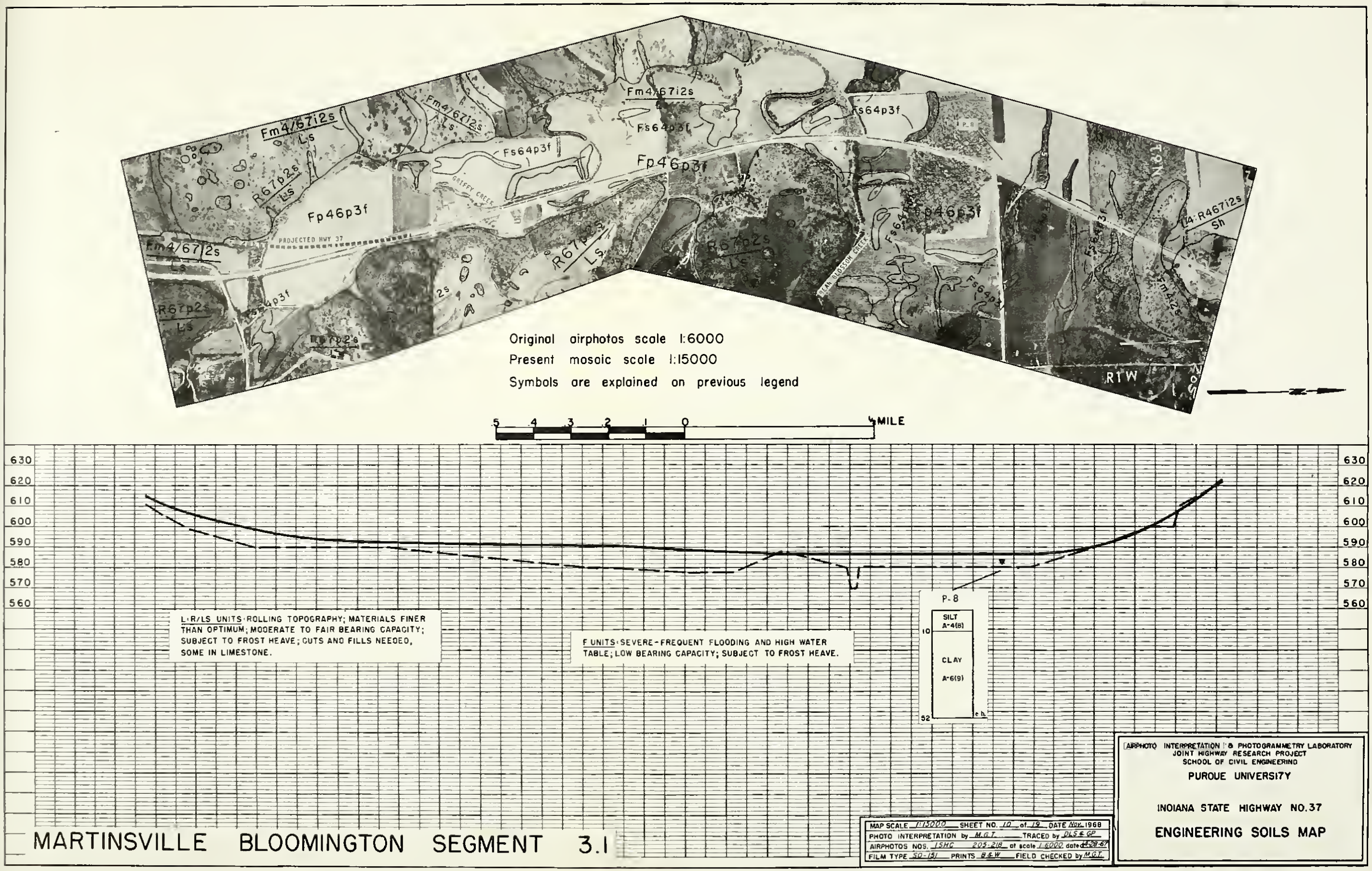
MARTINSVILL

AIRPHOTO INTERPRETATION & PHOTOGRAMMETRY LABORATORY
JOINT HIGHWAY RESEARCH PROJECT
SCHOOL OF CIVIL ENGINEERING

PURDUE UNIVERSITY

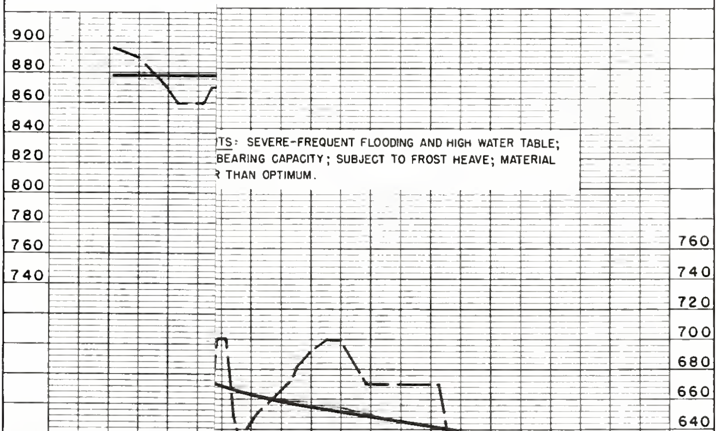
INDIANA STATE HIGHWAY NO. 37

ENGINEERING SOILS MAP



Fm4/67i2s Ls
Fm4/67i2s Ls
Fm4/67i2s
Fs64p3f
Fs64p3f
Fs64p3f
Fp46p3f
Fp46p3f
R67p2s Ls
R67p2s Ls
R67p2s Ls
R67p2s Ls
Fm4/67i2s Ls
GRIFFY CREEK
PROJECTED HWY 37
BEAN BLOSSOM CREEK
Fp46p3f
14: R467i2s Sh
T9N
R1W
Original airphotos scale 1:6000
Present mosaic scale 1:15000
Symbols are explained on previous legend
.5 .4 .3 .2 .1 0 ½ MILE
630
620
610
600
590
580
570
560
L-R/LS UNITS-ROLLING TOPOGRAPHY; MATERIALS FINER THAN OPTIMUM; MODERATE TO FAIR BEARING CAPACITY; SUBJECT TO FROST HEAVE; CUTS AND FILLS NEEDED, SOME IN LIMESTONE.
F UNITS-SEVERE-FREQUENT FLOODING AND HIGH WATER TABLE; LOW BEARING CAPACITY; SUBJECT TO FROST HEAVE.
P-8
SILT A-4(8)
10
CLAY A-6(9)
52
e.h.
MARTINSVILLE BLOOMINGTON SEGMENT 3.1
MAP SCALE 1:15000 SHEET NO. 10 of 19 DATE Nov. 1968
PHOTO INTERPRETATION by M.G.T. TRACED by DLS & GP
AIRPHOTOS NOS. ISHC 205-218 of scale 1:6000 dated
FILM TYPE SO-151 PRINTS B&W FIELD CHECKED by M.G.T.
AIRPHOTO INTERPRETATION & PHOTOGRAMMETRY LABORATORY
JOINT HIGHWAY RESEARCH PROJECT
SCHOOL OF CIVIL ENGINEERING
PURDUE UNIVERSITY
INDIANA STATE HIGHWAY NO.37
ENGINEERING SOILS MAP

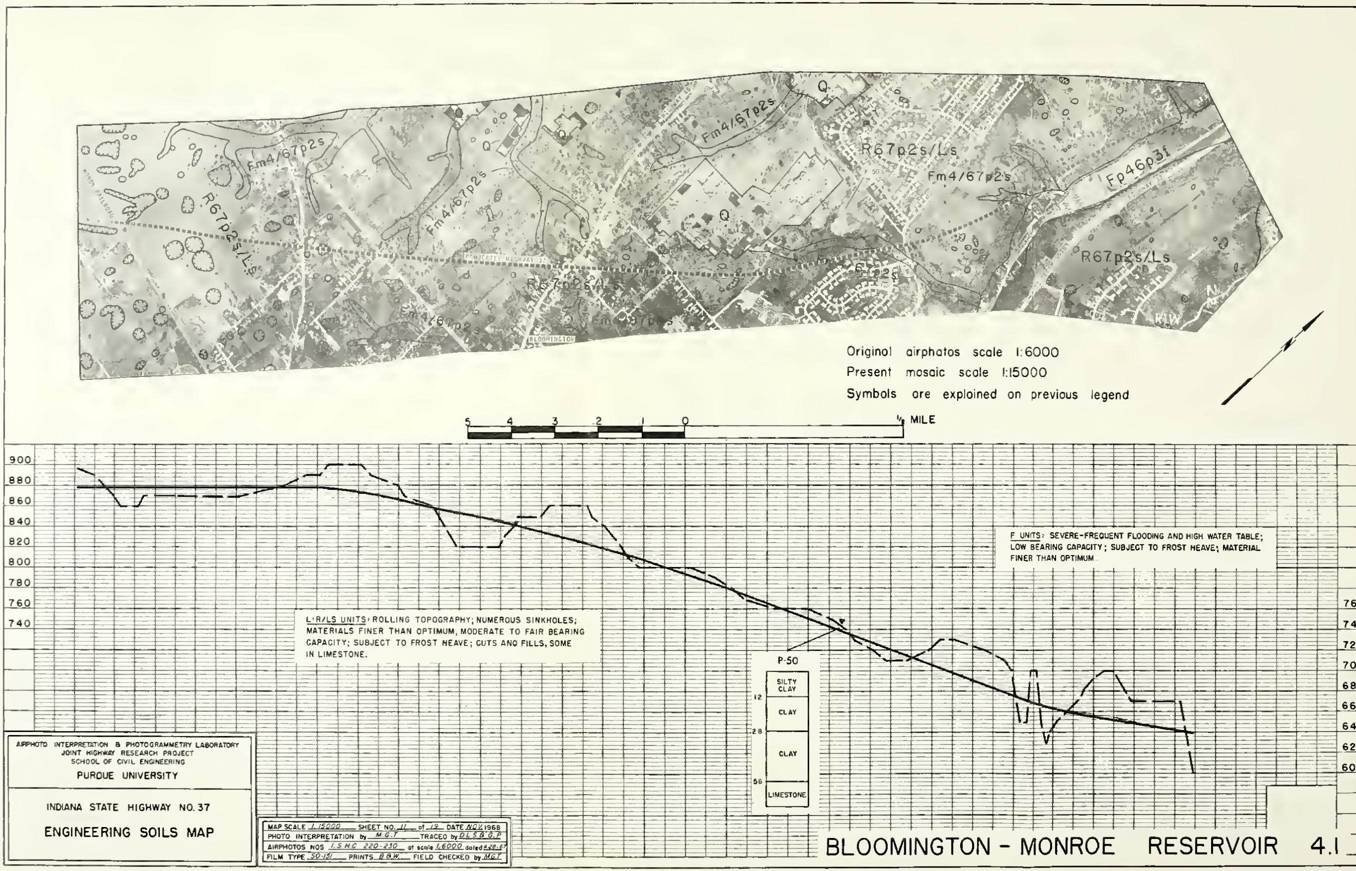
000
00
previous legend

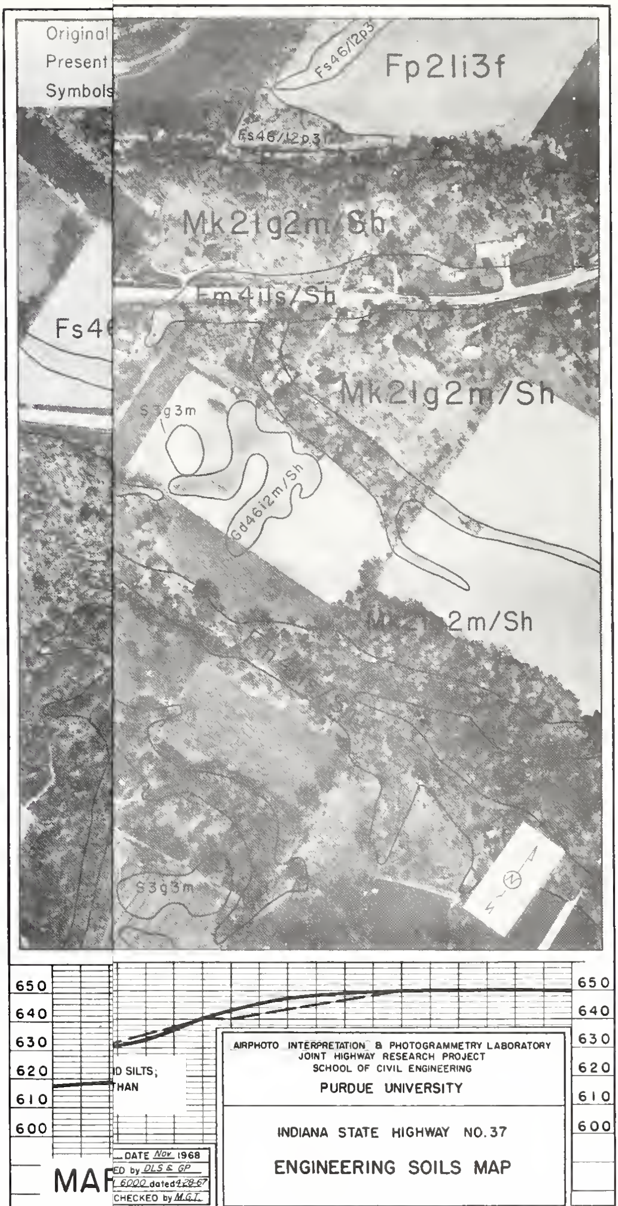


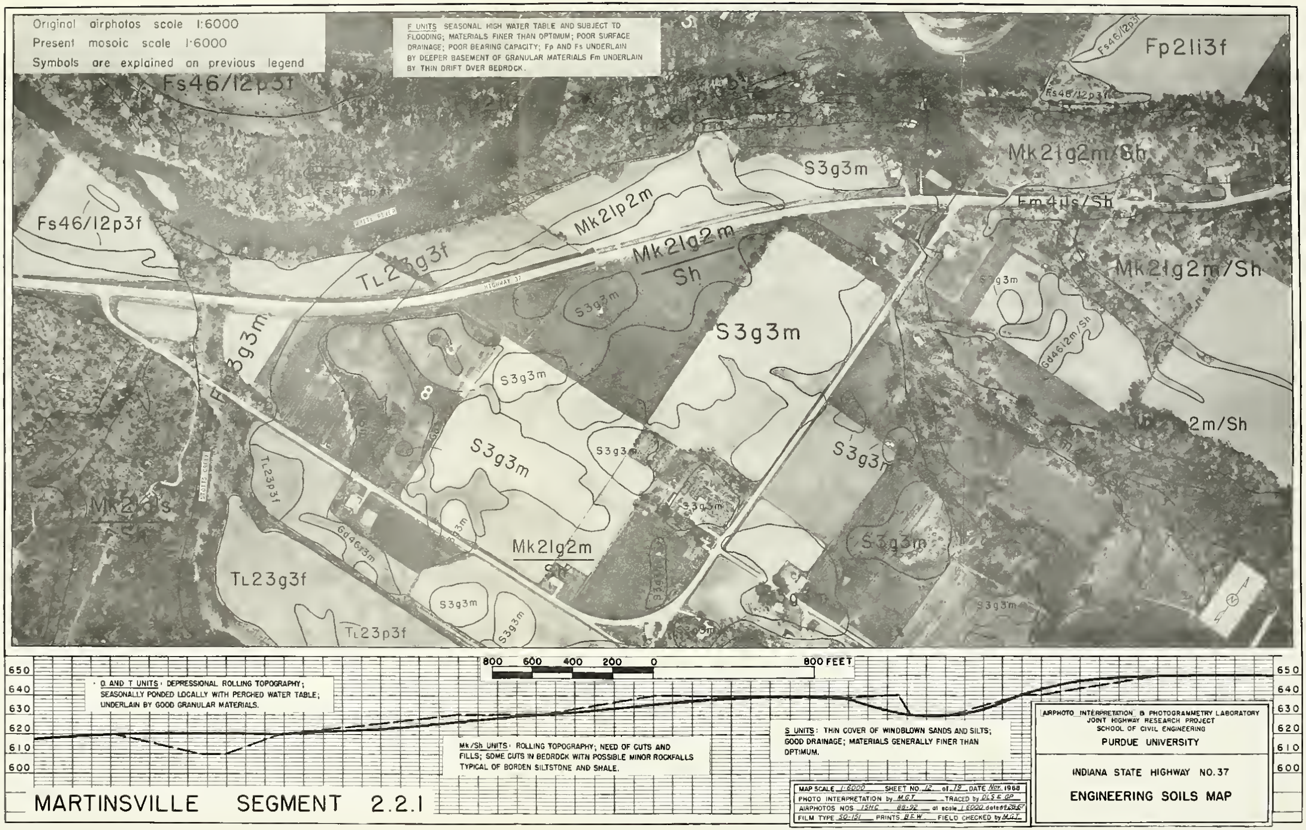
AIRPHOTO INTERPRETATION & PHOTO
JOINT HIGHWAY RESEAR
SCHOOL OF CIVIL EN
PURDUE UNIVE

INDIANA STATE HIGH

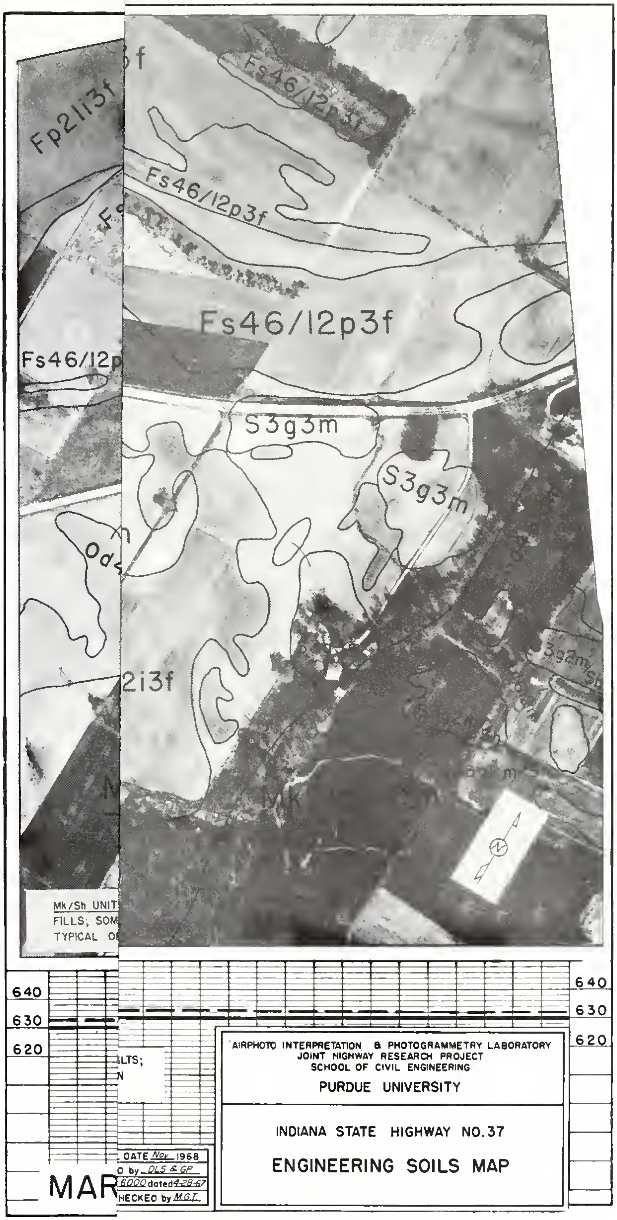
ENGINEERING S MONROE RESERVOIR 4.1

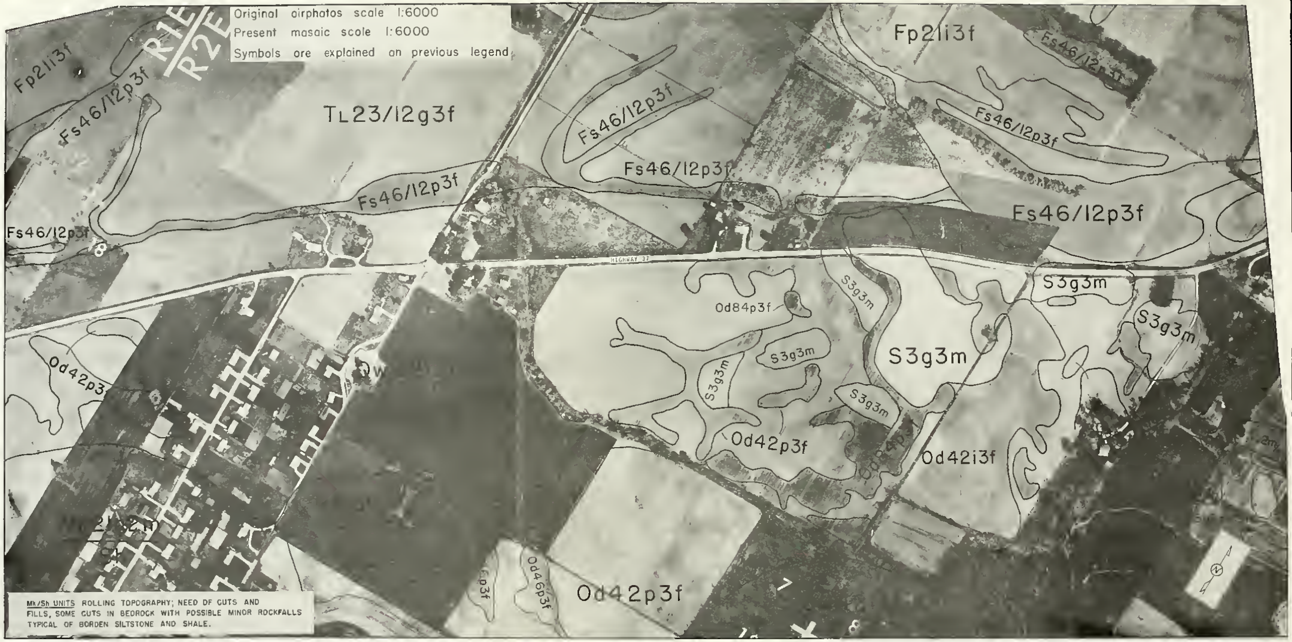

Fm4/67p2s
R67p2s/Ls
Fm4/67p2s
Fm4/67p2s
Fm4/67p2s
R67p2s/Ls
Fm4/67p2s
Fp46p3f
R67p2s/Ls
Q
Q
Q
Q
Q
Original airphotos scale 1:6000
Present mosaic scale 1:15000
Symbols are explained on previous legend
5 4 3 2 1 0 ½ MILE
900
880
860
840
820
800
780
760
740
760
740
720
700
680
660
640
620
600
F UNITS: SEVERE-FREQUENT FLOODING AND HIGH WATER TABLE; LOW BEARING CAPACITY; SUBJECT TO FROST HEAVE; MATERIAL FINER THAN OPTIMUM
L-R/LS UNITS: ROLLING TOPOGRAPHY; NUMEROUS SINKHOLES; MATERIALS FINER THAN OPTIMUM; MODERATE TO FAIR BEARING CAPACITY; SUBJECT TO FROST HEAVE; CUTS AND FILLS, SOME IN LIMESTONE.
P-50
SILTY CLAY
12
CLAY
28
CLAY
56
LIMESTONE
AIRPHOTO INTERPRETATION & PHOTOGRAMMETRY LABORATORY
JOINT HIGHWAY RESEARCH PROJECT
SCHOOL OF CIVIL ENGINEERING
PURDUE UNIVERSITY
INDIANA STATE HIGHWAY NO. 37
ENGINEERING SOILS MAP
MAP SCALE 1:15000 SHEET NO. 11 of 19 DATE NOV 1968
PHOTO INTERPRETATION by M.G.T. TRACED by D.L.S. B.G.P.
AIRPHOTOS NOS I.S.H.C. 220-230 at scale 1:6000 dated 4-28-67
FILM TYPE SO-151 PRINTS B&W FIELD CHECKED by M.G.T.
BLOOMINGTON - MONROE RESERVOIR 4.1


Original
Present
Symbols
Fp2li3f
Fs46/12p3
Fs46/12p3l
Mk2lg2m/Sh
Em4ils/Sh
Fs4
Mk2lg2m/Sh
S3g3m
Gd46i2m/Sh
2m/Sh
S3g3m
650
640
630
620
610
600
D SILTS;
THAN
AIRPHOTO INTERPRETATION & PHOTOGRAMMETRY LABORATORY
JOINT HIGHWAY RESEARCH PROJECT
SCHOOL OF CIVIL ENGINEERING
PURDUE UNIVERSITY
INDIANA STATE HIGHWAY NO. 37
ENGINEERING SOILS MAP
DATE Nov 1968
ED by DLS & GP
6000 dated 4-28-67
CHECKED by M.G.T.
MAF



Original airphotos scale 1:6000
Present mosaic scale 1:6000
Symbols are explained on previous legend
F UNITS SEASONAL HIGH WATER TABLE AND SUBJECT TO FLOODING; MATERIALS FINER THAN OPTIMUM; POOR SURFACE DRAINAGE; POOR BEARING CAPACITY; Fp AND Fs UNDERLAIN BY DEEPER BASEMENT OF GRANULAR MATERIALS Fm UNDERLAIN BY THIN DRIFT OVER BEDROCK.
Fs46/12p3f
Fp21i3f
Fs46/12p3f
Mk21g2m/Sh
S3g3m
Fm41s/Sh
Fs46/12p3f
Mk21p2m
Mk21g2m
Sh
TL23g3f
HIGHWAY 37
Mk21g2m/Sh
S3g3m
S3g3m
S3g3m
Gd4612m/Sh
S3g3m
2m/Sh
S3g3m
S3g3m
S3g3m
TL23p3f
Mk21g2m
Sh
S3g3m
TL23g3f
S3g3m
TL23p3f
S3g3m
800 600 400 200 0 800 FEET
650
640
630
620
610
600
Q AND T UNITS: DEPRESSIONAL ROLLING TOPOGRAPHY; SEASONALLY PONDED LOCALLY WITH PERCHED WATER TABLE; UNDERLAIN BY GOOD GRANULAR MATERIALS.
Mk/Sh UNITS: ROLLING TOPOGRAPHY; NEED OF CUTS AND FILLS; SOME CUTS IN BEDROCK WITH POSSIBLE MINOR ROCKFALLS TYPICAL OF BORDEN SILTSTONE AND SHALE.
S UNITS: THIN COVER OF WINDBLOWN SANDS AND SILTS; GOOD DRAINAGE; MATERIALS GENERALLY FINER THAN OPTIMUM.
MARTINSVILLE SEGMENT 2.2.1
MAP SCALE 1:6000 SHEET NO. 12 of 19 DATE Nov. 1968
PHOTO INTERPRETATION by M.G.T. TRACED by DLS & GP
AIRPHOTOS NOS ISHC 88-92 at scale 1:6000
FILM TYPE SO-151 PRINTS B&W FIELD CHECKED by M.G.T.
AIRPHOTO INTERPRETATION & PHOTOGRAMMETRY LABORATORY
JOINT HIGHWAY RESEARCH PROJECT
SCHOOL OF CIVIL ENGINEERING
PURDUE UNIVERSITY
INDIANA STATE HIGHWAY NO. 37
ENGINEERING SOILS MAP


Fp2i3f
Fs46/12p3f
Fs46/12p3f
Fs46/12p3f
Fs46/12p
S3g3m
S3g3m
Od4
2i3f
Mk
3g2m/Sh
Mk/Sh UNIT
FILLS; SOM
TYPICAL OF
640
630
620
640
630
620
LTS;
N
AIRPHOTO INTERPRETATION & PHOTOGRAMMETRY LABORATORY
JOINT HIGHWAY RESEARCH PROJECT
SCHOOL OF CIVIL ENGINEERING
PURDUE UNIVERSITY
INDIANA STATE HIGHWAY NO. 37
ENGINEERING SOILS MAP
DATE Nov 1968
O by DLS & GP
6000 dated 4-28-67
HECKED by M.G.T.
MAR



640
630
620

800 600 400 200 0 800 FEET

O AND T UNITS: DEPRESSIONAL ROLLING TOPOGRAPHY; SEASONALLY PONDED LOCALLY WITH PERCHED WATER TABLE; UNDERLAIN BY GOOD GRANULAR MATERIALS

F UNITS SEASONAL HIGH WATER TABLE AND SUBJECT TO FLOODING; MATERIALS FINER THAN OPTIMUM; POOR SURFACE DRAINAGE; POOR BEARING CAPACITY; Fp AND Fs UNDERLAIN BY DEEPER BASEMENT OF GRANULAR MATERIALS Fm UNDERLAIN BY THIN DRIFT OVER BEDROCK.

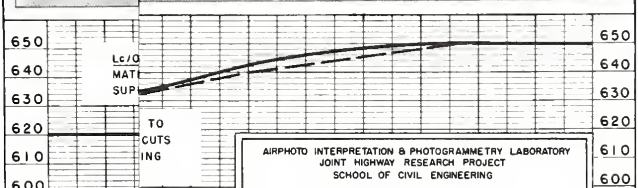
S UNITS: THIN COVER OF WINDBLOWN SANDS AND SILTS; GOOD DRAINAGE; MATERIALS GENERALLY FINER THAN OPTIMUM.

AIRPHOTO INTERPRETATION & PHOTOGRAMMETRY LABORATORY
JOINT HIGHWAY RESEARCH PROJECT
SCHOOL OF CIVIL ENGINEERING
PURDUE UNIVERSITY

INDIANA STATE HIGHWAY NO. 37
ENGINEERING SOILS MAP

MARTINSVILLE SEGMENT 2.2.2

MAP SCALE 1:6000 SHEET NO. 13 of 19 DATE Nov 1968
PHOTO INTERPRETATION by M.G.T. TRACED by DLS & GP
AIRPHOTOS NOS. ISHC 94-98 at scale 1:6000 dated 4-28-67
FILM TYPE 50-151 PRINTS B & W FIELD CHECKED by M.G.T.



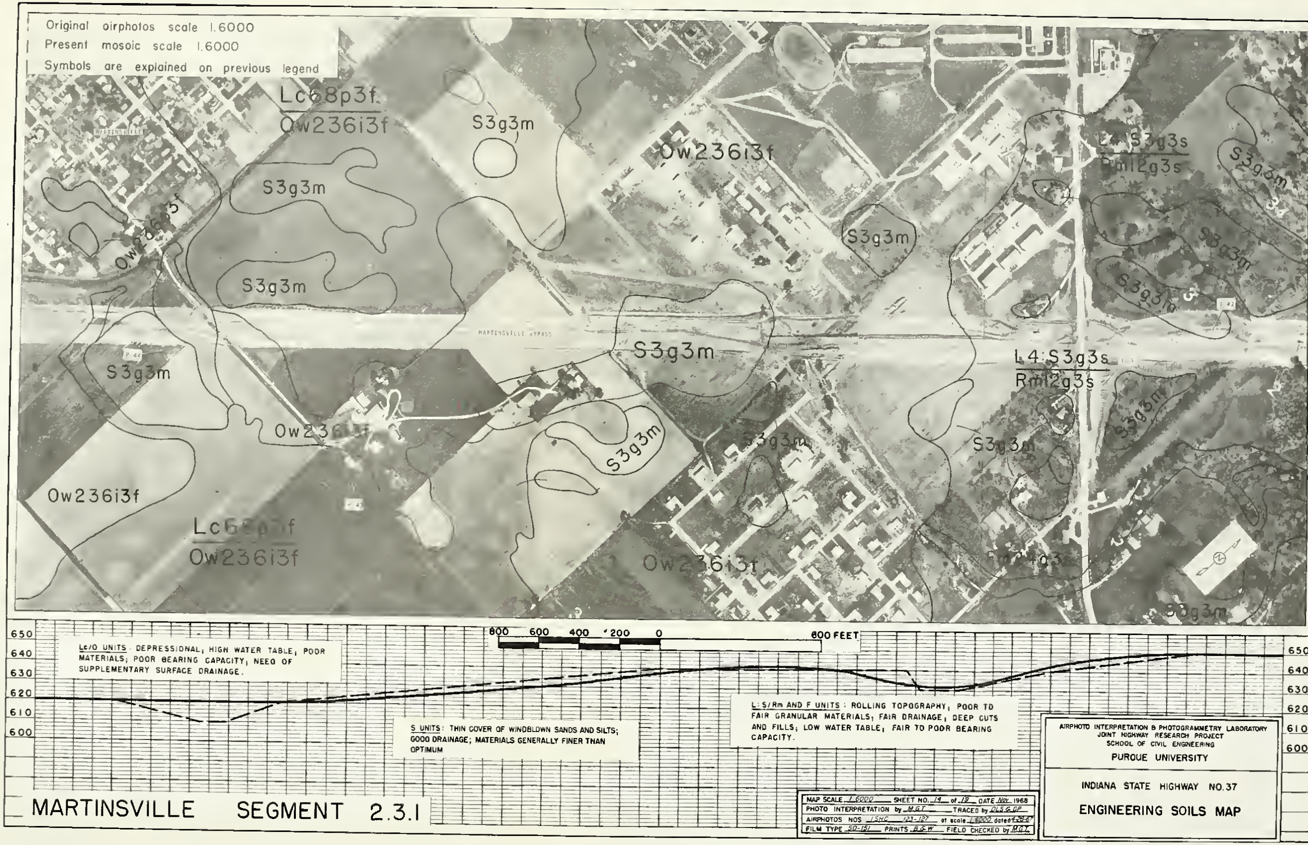
DATE Nov 1968
D by DLS & GP
6000 dated 4-28-67
HECKED by M.G.T.

MART

AIRPHOTO INTERPRETATION & PHOTOGRAMMETRY LABORATORY
JOINT HIGHWAY RESEARCH PROJECT
SCHOOL OF CIVIL ENGINEERING
PURDUE UNIVERSITY

INDIANA STATE HIGHWAY NO. 37

ENGINEERING SOILS MAP


Original airphotos scale 1:6000
Present mosaic scale 1:6000
Symbols are explained on previous legend
Lc68p3f
Ow236i3f
S3g3m
Ow236i3f
S3g3m
S3g3m
S3g3m
Ow236i3f
L4:S3g3s
Rm12g3s
S3g3m
S3g3m
S3g3m
S3g3m
L4:S3g3s
Rm12g3s
S3g3m
S3g3m
Ow236i3f
S3g3m
S3g3m
Ow236i3f
Lc68p3f
Ow236i3f
Ow236i3f
S3g3m
650
640
630
620
610
600
Lc/O UNITS: DEPRESSIONAL, HIGH WATER TABLE, POOR MATERIALS; POOR BEARING CAPACITY, NEED OF SUPPLEMENTARY SURFACE DRAINAGE.
800 600 400 200 0 600 FEET
S UNITS: THIN COVER OF WINDBLOWN SANDS AND SILTS; GOOD DRAINAGE; MATERIALS GENERALLY FINER THAN OPTIMUM
L: S/Rm AND F UNITS: ROLLING TOPOGRAPHY, POOR TO FAIR GRANULAR MATERIALS, FAIR DRAINAGE, DEEP CUTS AND FILLS; LOW WATER TABLE, FAIR TO POOR BEARING CAPACITY.
650
640
630
620
610
600
AIRPHOTO INTERPRETATION & PHOTOGRAMMETRY LABORATORY
JOINT HIGHWAY RESEARCH PROJECT
SCHOOL OF CIVIL ENGINEERING
PURDUE UNIVERSITY
INDIANA STATE HIGHWAY NO. 37
ENGINEERING SOILS MAP
MAP SCALE 1:6000 SHEET NO. 14 of 19 DATE Nov 1968
PHOTO INTERPRETATION by M.G.T. TRACED by DLS & GP
AIRPHOTOS NOS ISHC 123-127 at scale 1:6000 dated 4-28-67
FILM TYPE SO-151 PRINTS B&W FIELD CHECKED by M.G.T.
MARTINSVILLE SEGMENT 2.3.1

These photo-maps show examples of different terrain conditions: Plates 6 and 7 show predominance of glacial terrain and minor drainage ways; Plate 8 shows a combination of glacial terrain, outwash and flood plain; Plate 9 is characterized by a ridge moraine covered with minor loess and sands adjoining a lacustrine plain covering outwash; Plate 10 represents a glacial sluiceway [246] cutting across a limestone plain; Plate 11 is characterized by limestone terrain.

From these maps it can be shown also that the reliability of inference improves as the scale becomes larger, (see Plates 2, 8, 12 and also Plates 2, 9, 14). The production of these photo-maps showed a considerable increase in photo-interpretation time for the very detailed mapping (see Table 5). It was found that the photo-interpretation time increased by a factor going from 1.7 to 2.0 when considering the time taken to interprete what is shown on Plates 12 and 13 as compared to the time for the "parent" map on Plate 8. This factor reached a value of 2.9 for Plate 14 compared to Plate 9.

3.25 Engineering Soil Maps from Color Aerial Photographs

In order to compare color with black and white aerial photographs and investigate the contribution of color in terms of improved engineering soil mapping, five different color mosaics were assembled and annotated with the interpreted soil boundaries. Because of too expensive a cost of color mosaic reproduction, the information was transferred to the black and white photo-maps used as a base, just as was done for the mapping with black and white photography.

The interpretation obtained from the color photographs are shown on

TABLE 5

COMPARATIVE PHOTO-INTERPRETATION TIMES				
Photo-Map No.	Scale (sq. mi)	Area (sq. mi)	P. I. Total Time (hours)	Normalized P.I. Time (hours/sq. mi)
1 to 5	1:20,000	350.	120.	0.34
(9 photo-maps)	1:12,000	134.	44.	0.33
1.1	1:4,800	2.48	3.0	1.21
2.1	1:4,800	2.46	2.25	0.915
2.2	1:4,800	2.32	6.5	2.80
2.3	1:4,800	2.46	4.0	1.62
3.1	1:4,800	2.02	5.0	2.48
4.1	1:4,800	2.17	3.5	1.61
2.2.1	1:4,800	0.85	4.0	4.71
2.2.2	1:4,800	0.825	4.5	5.45
2.3.1	1:4,800	0.85	4.0	4.71
2.3(C)	1:4,800	2.02	2.5	1.24 (23.4%)
3.1(C)	1:4,800	1.70	2.5	1.47 (40.8%)
4.1(C)	1:4,800	1.80	2.0	1.11 (31.0%)
2.2.1(C)	1:4,800	0.72	2.0	2.78 (41.0%)
2.2.2(C)	1:4,800	0.85	2.75	3.24 (40.5%)

$$\frac{(\text{Norm. Time})_{2.3(C)}}{(\text{Norm. Time})_{2.3}} = \frac{(\text{N.T.})_{2.3(C)}}{(\text{N.T.})_{2.3}} = \frac{1.24}{1.62} = 0.766$$

TIME ECONOMY FOR COLOR P. I. = (1.00 - .766) 100 = 23.4%

$$\frac{(\text{N.T.})_{3.1(C)}}{(\text{N.T.})_{3.1}} = \frac{1.47}{2.48} = 0.592 \; ; \; \frac{(\text{N.T.})_{4.1(C)}}{(\text{N.T.})_{4.1}} = \frac{1.11}{1.61} = 0.69 \; ;$$

$$\frac{(\text{N.T.})_{2.2.1(C)}}{(\text{N.T.})_{2.2.1}} = \frac{2.78}{4.71} = 0.59 \; ; \; \frac{(\text{N.T.})_{2.2.2(C)}}{(\text{N.T.})_{2.2.2}} = \frac{3.24}{5.45} = 0.595$$

Plates 15 to 19 included. The identification numbers of these photo-maps are followed by the capital letter "C", indicating that the information was obtained from color aerial photographs.

The color prints were prepared from Kodak Ektachrome-MS film developed to a negative. Only proof prints were used, the color balanced prints being too expensive. The color proof prints are of sufficient quality for interpretation purposes herein described.

When comparing the two sets of photo-maps, those from black and white photos (Plates 9 to 13) with those from the color photographs (Plates 15 to 19), one can observe that there are relatively minor differences in terms of location of soil boundaries and symbols used. This is explained by the fact that engineering soils mapping has been developed "principally" on the basis of the land form-parent material relationship, and not on colors of the soils.

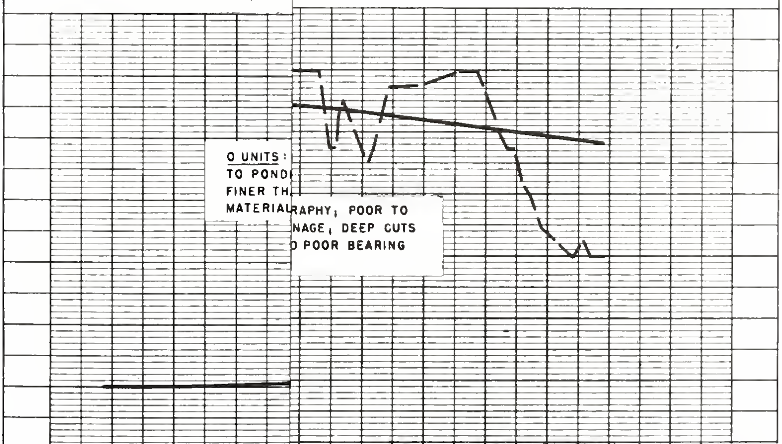
Color is an asset for mapping engineering soils. The soils boundaries can be located with much greater precision and the interpretation is much more accurate. When comparing photo-maps 2.3 and 2.3(C), (Plates 9 and 15), it was found that color assisted in locating and identifying a muck pocket (M8p3f), in identifying additional soil zones, depressional conditions with various degrees of moisture and additional third order land forms (Gd46p3m). Figure 38 shows samples of two photo-mosaics, one in color the other in black and white. This example is brought in to show that soil boundaries can be traced more easily and more accurately on the color mosaic.

When comparing photo-maps 3.1 and 3.1(C) (Plates 10 and 16), it was observed that color did help produce a more accurate interpretation. In

Original airphotos sc

Present masaic scal

Symbols are explain



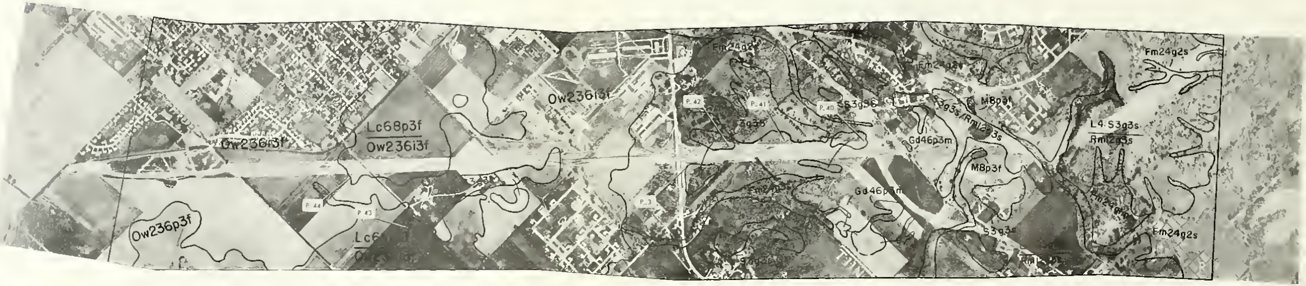
MARTINSVILL

DATE NOV. 19
by D.L.S. & G.P.
000 dated 4-28-57
HECKED by M.G.T.

AIRPHOTO INTERPRETATION & PHOTOGRAMMETRY LABORATORY
JOINT HIGHWAY RESEARCH PROJECT
SCHOOL OF CIVIL ENGINEERING
PURDUE UNIVERSITY

INDIANA STATE HIGHWAY NO.37

ENGINEERING SOILS MAP

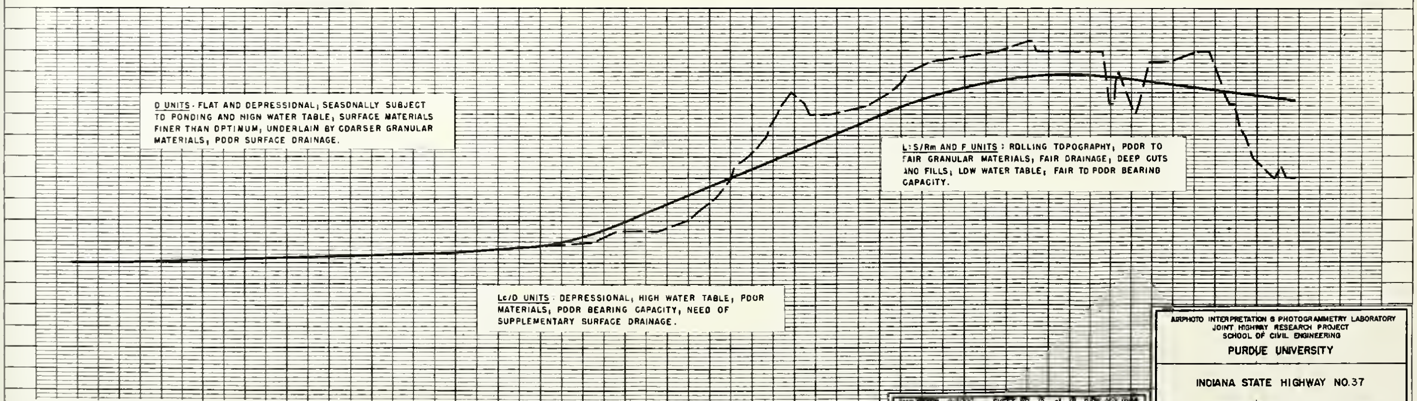


Original airphotos scale 1:6000

Present mosaic scale 1:15000

Symbols are explained on previous legend

.5 .4 .3 .2 .1 0 ½ MILE



MARTINSVILLE SEGMENT 2.3 (C)

MAP SCALE [illegible] SHEET NO 15 of 19 DATE [illegible]
PHOTO INTERPRETATION by M.G.T. TRACED by D.L.S. & G.P.
AIRPHOTOS NOS. I.S.H.C. 117-129 at scale 1:6000 dated [illegible]
FILM TYPE SO-151 PRINTS COLOR FIELD CHECKED by M.G.T.

AIRPHOTO INTERPRETATION & PHOTOGRAMMETRY LABORATORY
JOINT HIGHWAY RESEARCH PROJECT
SCHOOL OF CIVIL ENGINEERING
PURDUE UNIVERSITY

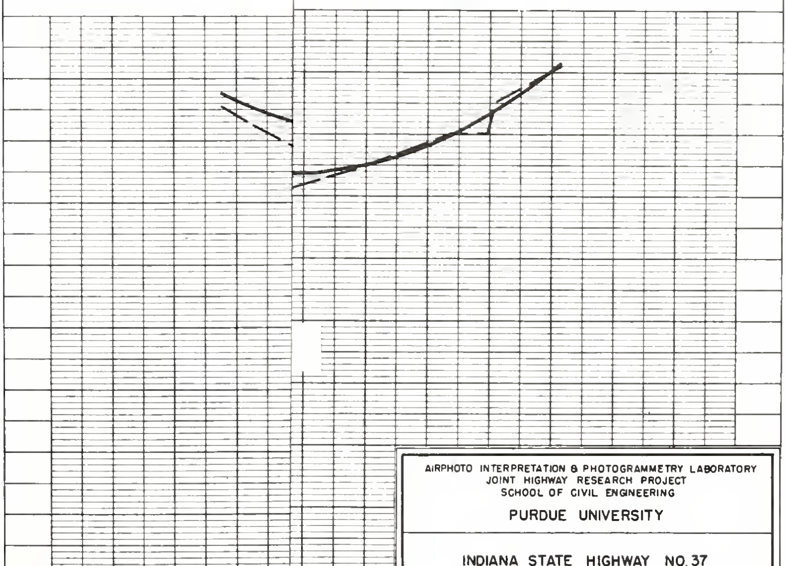
INDIANA STATE HIGHWAY NO. 37

ENGINEERING SOILS MAP

Original airphotos scal

Present mosaic scale

Symbols are explained



MARTINSVILL

DATE NOV. 1968

D by DLS & GP

6000 dated 4-28-67

CHECKED by MGT.

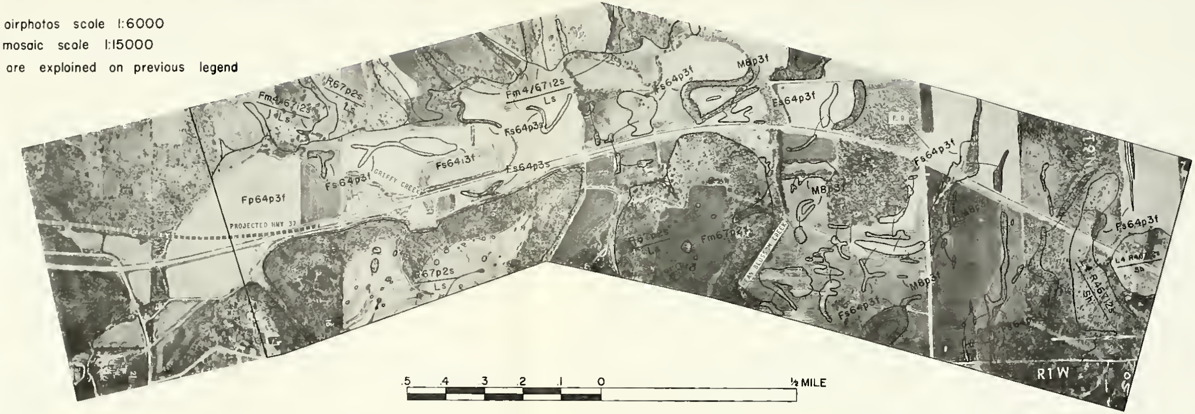
AIRPHOTO INTERPRETATION & PHOTOGRAMMETRY LABORATORY
JOINT HIGHWAY RESEARCH PROJECT
SCHOOL OF CIVIL ENGINEERING

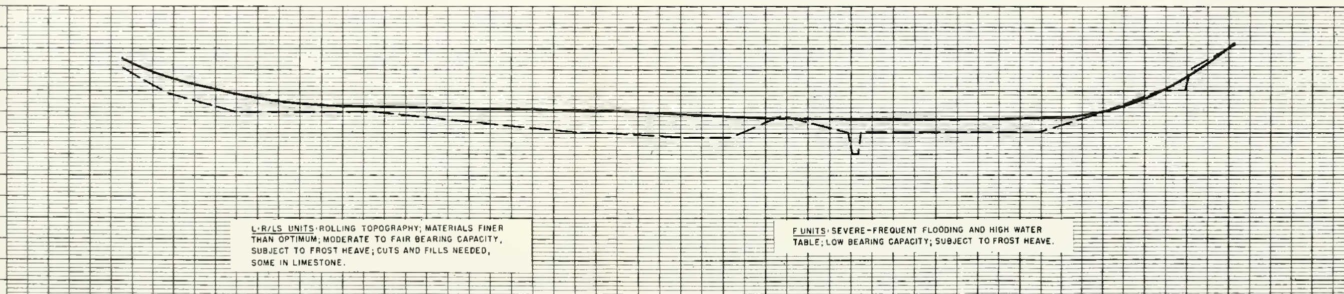
PURDUE UNIVERSITY

INDIANA STATE HIGHWAY NO. 37

ENGINEERING SOILS MAP

Original airphotos scale 1:6000
Present mosaic scale 1:15000
Symbols are explained on previous legend





L-R/LS UNITS: ROLLING TOPOGRAPHY; MATERIALS FINER THAN OPTIMUM; MODERATE TO FAIR BEARING CAPACITY, SUBJECT TO FROST HEAVE; CUTS AND FILLS NEEDED, SOME IN LIMESTONE.

F UNITS: SEVERE-FREQUENT FLOODING AND HIGH WATER TABLE; LOW BEARING CAPACITY; SUBJECT TO FROST HEAVE.

MARTINSVILLE BLOOMINGTON SEGMENT 3.1 (C)

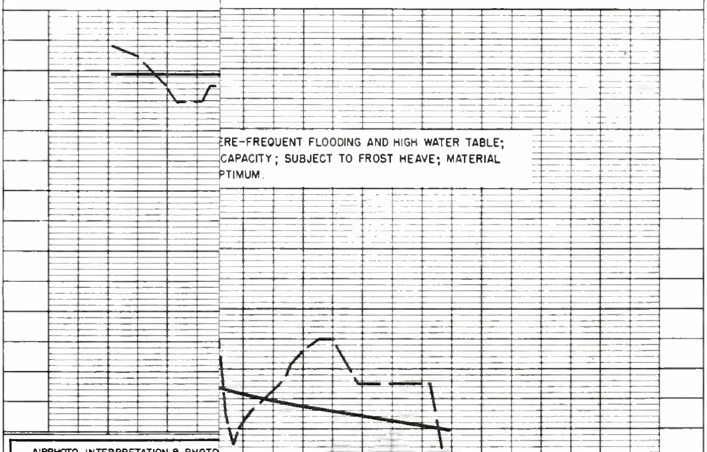
MAP SCALE 1:15000	SHEET NO. 16 of 19 DATE NOV 1968
PHOTO INTERPRETATION by M.G.T.	TRACED by D.L.S. & G.P.
AIRPHOTOS NOS. I.S.H.C. 205-218	at scale 1:6000 dated 4-28-67
FILM TYPE SO-151 PRINTS COLOR	FIELD CHECKED by M.G.T.

AIRPHOTO INTERPRETATION & PHOTOGRAMMETRY LABORATORY
JOINT HIGHWAY RESEARCH PROJECT
SCHOOL OF CIVIL ENGINEERING
PURDUE UNIVERSITY

INDIANA STATE HIGHWAY NO. 37

ENGINEERING SOILS MAP

riginal airphotos scale 1:6000
resent mosaic scale 1:15000
ymbols are explained on previous legend



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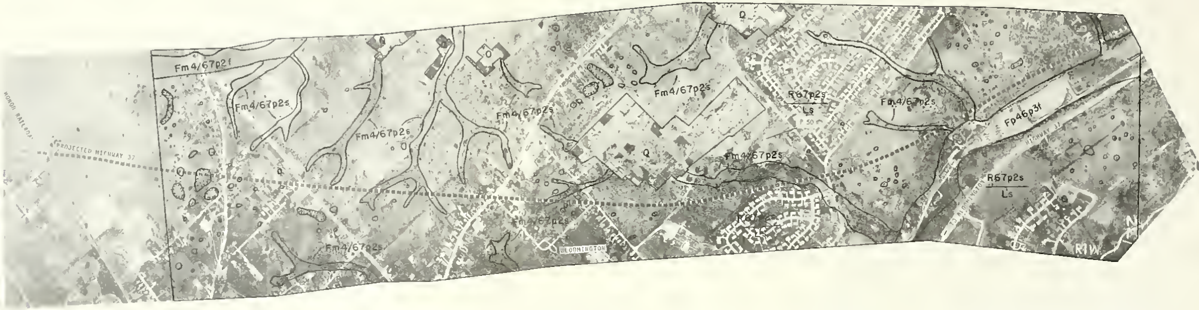
PURDUE UNIVE

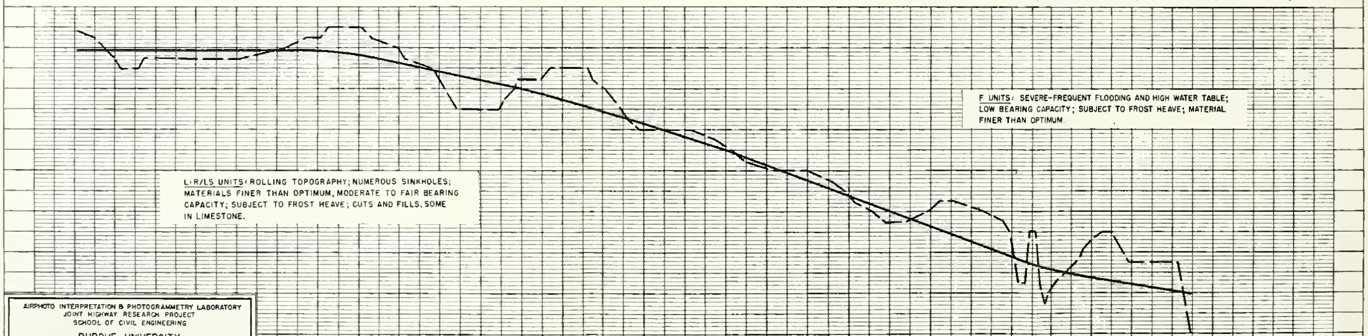
INDIANA STATE HIGH

ENGINEERING S OE RESERVOIR 4.1 (C)



.5 .4 .3 .2 .1 0 ½ MILE

Original airphotos scale 1:6000
Present mosaic scale 1:15000
Symbols are explained on previous legend



AIRPHOTO INTERPRETATION & PHOTOGRAMMETRY LABORATORY
JOINT HIGHWAY RESEARCH PROJECT
SCHOOL OF CIVIL ENGINEERING
PURDUE UNIVERSITY

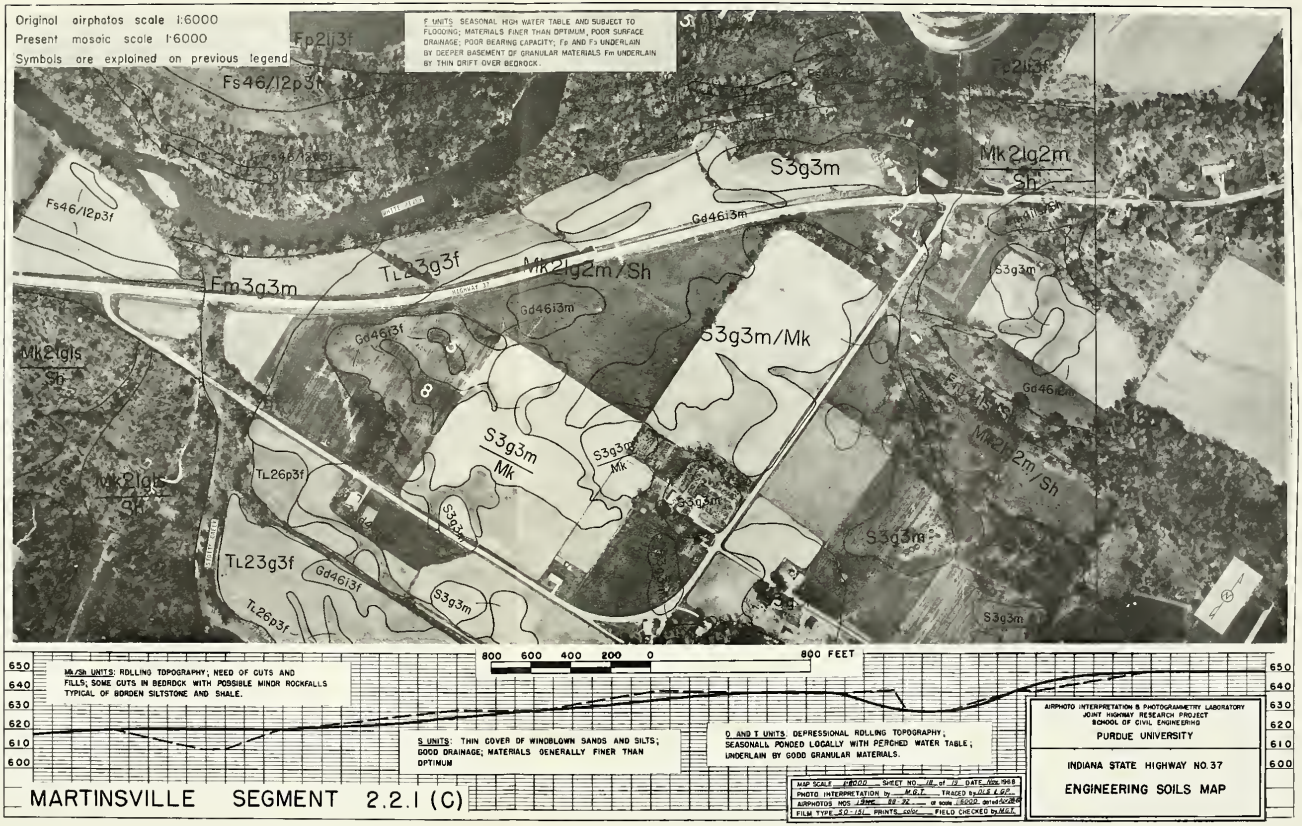
INDIANA STATE HIGHWAY NO. 37

ENGINEERING SOILS MAP

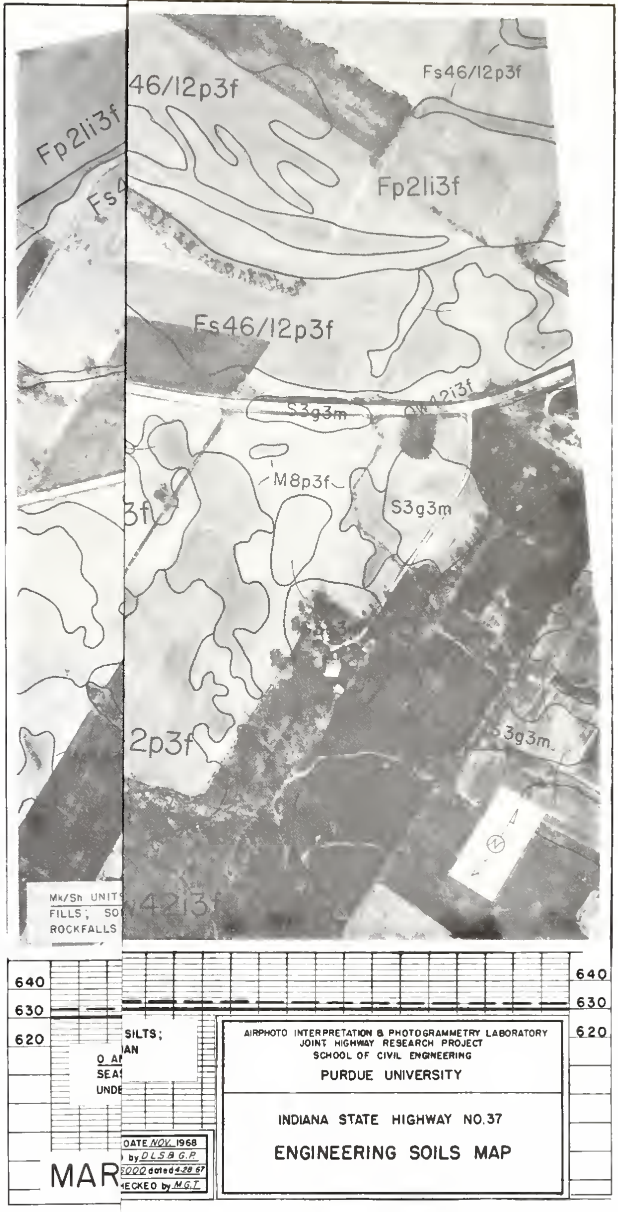
MAP SCALE 1:15000 SHEET NO 17 of 19 DATE NOV. 1968
PHOTO INTERPRETATION by M.G.T. TRACED by D.L.S.&G.P.
AIRPHOTOS NOS I.S.H.C. 220-230 at scale 1:6000 dated 4-28-67
FILM TYPE SO-151 PRINTS COLOR FIELD CHECKED by M.G.T.

BLOOMINGTON - MONROE RESERVOIR 4.1 (C)


Original ai
Present m
Symbols a
Fp2li3f
Mk2lg2m
Sh
Fs46
S3g3m
Mk2lgl
Sh
Gd46l2m
Mk2lg2m/Sh
S3g3m
650
640
630
620
610
600
MAR
DATE Nov. 1968
CHECKED by M.G.T.
AIRPHOTO INTERPRETATION & PHOTOGRAMMETRY LABORATORY
JOINT HIGHWAY RESEARCH PROJECT
SCHOOL OF CIVIL ENGINEERING
PURDUE UNIVERSITY
INDIANA STATE HIGHWAY NO. 37
ENGINEERING SOILS MAP



Original airphotos scale 1:6000
Present mosaic scale 1:6000
Symbols are explained on previous legend
F UNITS SEASONAL HIGH WATER TABLE AND SUBJECT TO FLOODING; MATERIALS FINER THAN OPTIMUM, POOR SURFACE DRAINAGE; POOR BEARING CAPACITY; Fp AND Fs UNDERLAIN BY DEEPER BASEMENT OF GRANULAR MATERIALS Fm UNDERLAIN BY THIN DRIFT OVER BEDROCK.
Fp2li3f
Fs46/12p3f
Fs46/12p3f
Tp2li3f
S3g3m
Mk2lg2m/Sh
Gd46i3m
TL23g3f
Mk2lg2m/Sh
Fm3g3m
HIGHWAY 37
WHITE RIVER
Gd46i3m
S3g3m/Mk
Gd46i3f
8
Mk2lgls/Sh
S3g3m
S3g3m/Mk
S3g3m/Mk
S3g3m
Gd46i2m
Mk2li2m/Sh
TL26p3f
Mk2lgls/Sh
S3g3m
S3g3m
TL23g3f
Gd46i3f
S3g3m
TL26p3f
S3g3m
STOTTS CREEK
800 600 400 200 0 800 FEET
650
640
630
620
610
600
Mk/Sh UNITS: ROLLING TOPOGRAPHY; NEED OF CUTS AND FILLS; SOME CUTS IN BEDROCK WITH POSSIBLE MINOR ROCKFALLS TYPICAL OF BORDEN SILTSTONE AND SHALE.
S UNITS: THIN COVER OF WINDBLOWN SANDS AND SILTS; GOOD DRAINAGE; MATERIALS GENERALLY FINER THAN OPTIMUM
D AND T UNITS: DEPRESSIONAL ROLLING TOPOGRAPHY; SEASONALL PONDED LOCALLY WITH PERCHED WATER TABLE; UNDERLAIN BY GOOD GRANULAR MATERIALS.
MARTINSVILLE SEGMENT 2.2.1 (C)
MAP SCALE 1:6000 SHEET NO. 18 of 19 DATE Nov. 1968
PHOTO INTERPRETATION by M.G.T. TRACED by DLS & GP
AIRPHOTOS NOS 19MC 88-92 at scale 1:6000 dated Apr 28 68
FILM TYPE SO-151 PRINTS color FIELD CHECKED by M.G.T.
AIRPHOTO INTERPRETATION & PHOTOGRAMMETRY LABORATORY
JOINT HIGHWAY RESEARCH PROJECT
SCHOOL OF CIVIL ENGINEERING
PURDUE UNIVERSITY
INDIANA STATE HIGHWAY NO. 37
ENGINEERING SOILS MAP



46/12p3f
Fs46/12p3f
Fp2li3f
Fs4
Fp2li3f
Fs46/12p3f
W42i3f
S3g3m
M8p3f
S3g3m
3f
2p3f
S3g3m
N
Mk/Sh UNITS
FILLS; SO
ROCKFALLS
W42i3f
640
630
620
640
630
620
SILTS;
AN
O AN
SEAS
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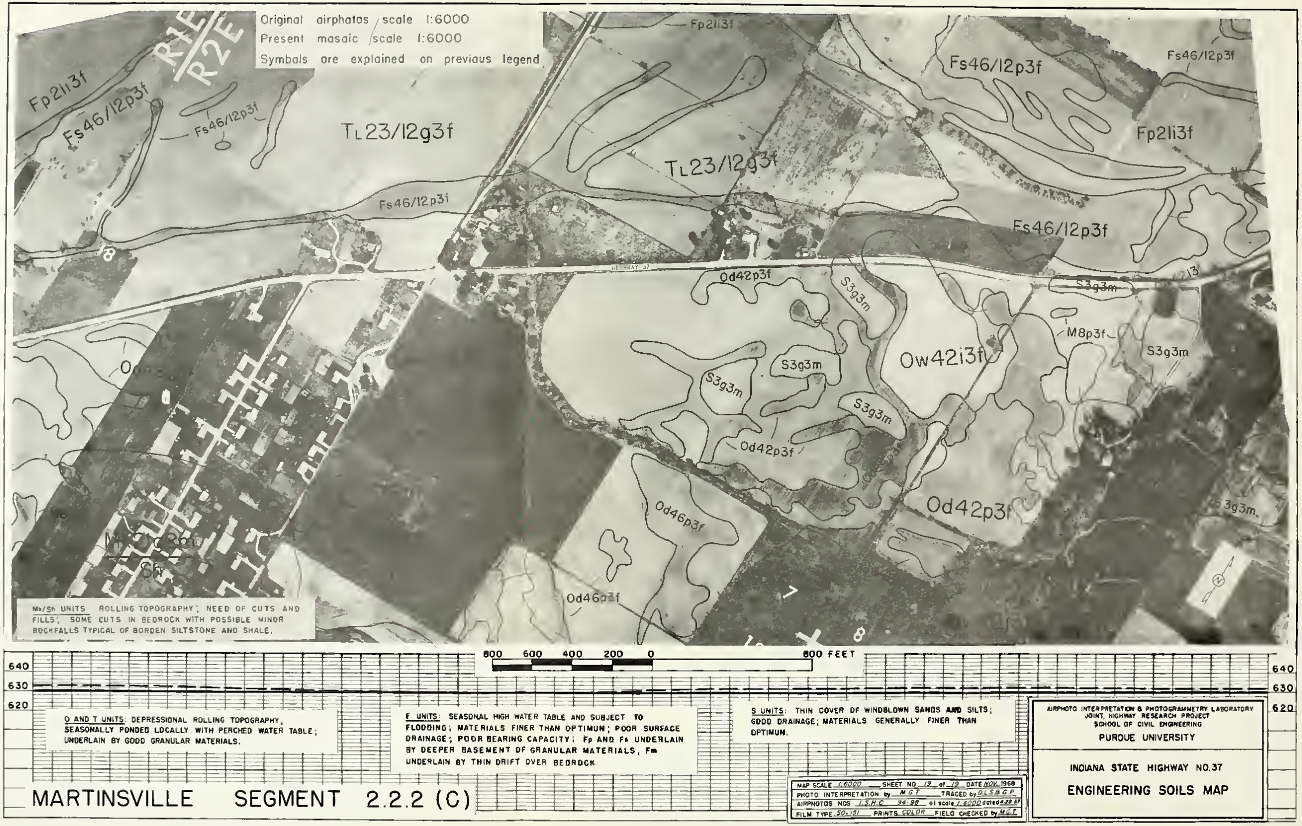
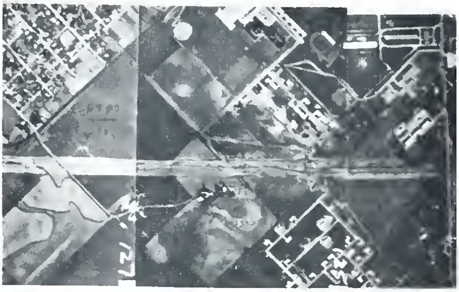
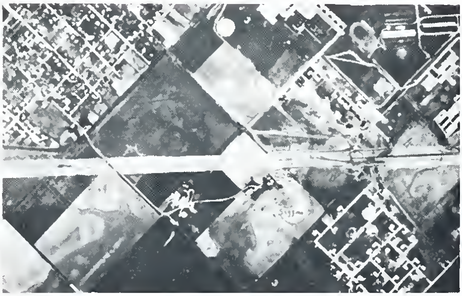
MAR
DATE NOV. 1968
by D.L.S. & G.P.
5000 dated 4-28-67
CHECKED by M.G.T.
AIRPHOTO INTERPRETATION & PHOTOGRAMMETRY LABORATORY
JOINT HIGHWAY RESEARCH PROJECT
SCHOOL OF CIVIL ENGINEERING
PURDUE UNIVERSITY
INDIANA STATE HIGHWAY NO. 37
ENGINEERING SOILS MAP


Original airphotos scale 1:6000
Present mosaic scale 1:6000
Symbols are explained on previous legend
R1E
R2E
Fp2li3f
Fs46/12p3f
TL23/12g3f
Fs46/12p3f
Fp2li3f
TL23/12g3f
Fs46/12p3f
Fs46/12p3f
Od42p3f
S3g3m
S3g3m
M8p3f
S3g3m
Ow42i3f
S3g3m
S3g3m
S3g3m
Od42p3f
Od42p3f
Od46p3f
Od46p3f
S3g3m
Mk/Sh UNITS ROLLING TOPOGRAPHY; NEED OF CUTS AND FILLS; SOME CUTS IN BEDROCK WITH POSSIBLE MINOR ROCKFALLS TYPICAL OF BORDEN SILTSTONE AND SHALE.
800 600 400 200 0 800 FEET
640
630
620
O AND T UNITS: DEPRESSIONAL ROLLING TOPOGRAPHY, SEASONALLY PONDED LOCALLY WITH PERCHED WATER TABLE; UNDERLAIN BY GOOD GRANULAR MATERIALS.
F UNITS: SEASONAL HIGH WATER TABLE AND SUBJECT TO FLOODING; MATERIALS FINER THAN OPTIMUN; POOR SURFACE DRAINAGE; POOR BEARING CAPACITY; Fp AND Fs UNDERLAIN BY DEEPER BASEMENT OF GRANULAR MATERIALS, Fm UNDERLAIN BY THIN DRIFT OVER BEDROCK.
S UNITS: THIN COVER OF WINDBLOWN SANDS AND SILTS; GOOD DRAINAGE; MATERIALS GENERALLY FINER THAN OPTIMUN.
MARTINSVILLE SEGMENT 2.2.2 (C)
MAP SCALE 1:6000 SHEET NO 19 of 19 DATE NOV. 1968
PHOTO INTERPRETATION by M G T TRACED by D.L.S.B.G.P.
AIRPHOTOS NOS I.S.H.C. 94-98 at scale 1:6000 dated 4-28-67
FILM TYPE SO-151 PRINTS COLOR FIELD CHECKED by M.G.T.
AIRPHOTO INTERPRETATION & PHOTOGRAMMETRY LABORATORY
JOINT, HIGHWAY RESEARCH PROJECT
SCHOOL OF CIVIL ENGINEERING
PURDUE UNIVERSITY
INDIANA STATE HIGHWAY NO.37
ENGINEERING SOILS MAP



COLOR MOSAIC



BLACK—WHITE MOSAIC

FIGURE 38 COMPARISON OF SAMPLE PHOTO—MOSAIC SHOWING PART OF PHOTO—MAPS 2.3 (C) AND 2.3

the vicinity of Bean Blossom Creek for instance, wet zones (Fs64p3f) and muck areas (M8p3f) were delineated with the aid of color, which could not be defined with the black and white photography as illustrated on Figure 39.

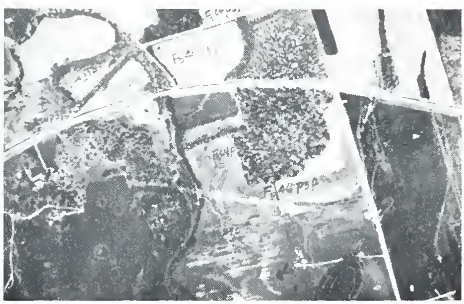
The comparison of photo-maps 4.1 and 4.1(C), (Plates 11 and 17) resulted in similar conclusions: greater accuracy at delineating soil boundaries and land forms and overall greater speed at interpreting the photos. Here the major advantage was found in being able to detect and identify a greater number of sinkholes and to delineate more easily land forms under a leafless tree-cover.

The comparison of photo-maps 2.2.1 and 2.2.1(C), (Plates 12 and 18), indicates the gain of information from color resulted in more precise boundaries. The increment of information was the identification and delineation of a greater number of soils features like silt mounds (S3g3m) and a faster and more accurate understanding of the soils distribution over the area. Part of this is illustrated on Figure 40 which shows two mosaics presented as samples taken from Plates 12 and 18.

The comparison of photo-maps 2.2.2 and 2.2.2(C), (Plates 13 and 19), indicated that in addition to more precise interpretation boundaries and additional soil area, a muck pocket of relatively large extent (lower left corner of Plate 13) had been identified and delineated as three small zones on the black and white photos. The color photos indicated the muck pocket as a single zone of much greater aerial extent (Plate 19). The color of the muck under the thin vegetative cover of winter wheat showed more distinctly than on the black and white.

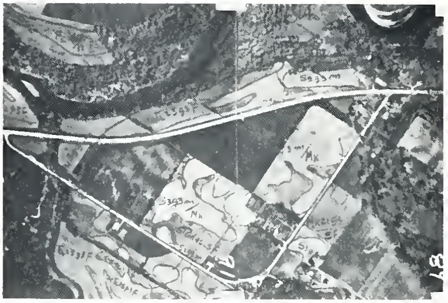
A few more cases are illustrated on Figures 41 and 42. Figure 41(a)

COLOR MOSAIC



BLACK-WHITE MOSAIC

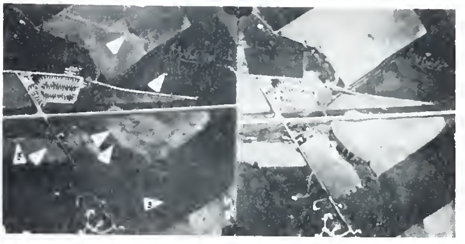
FIGURE 39. COMPARISON OF SAMPLE PHOTO-MOSAIC SHOWING PART OF PHOTO-MAPS 3.1 (C) AND 3.1



COLOR MOSAIC

BLACK–WHITE MOSAIC

FIGURE 40. COMPARISON OF SAMPLE PHOTO–MOSAICS SHOWING PART OF PHOTO–MAPS 2.2.1 (C) AND 2.2.1



COLOR BLACK AND WHITE

(A) [see photo-map 1.1]

COLOR BLACK AND WHITE

(B) [see photo-map 2.2.1(C)]

FIGURE 41. COMPARISON OF COLOR AND BLACK AND WHITE PHOTOGRAPHY IN TERMS OF SOIL BOUNDARY DELINEATION AND SOILS IDENTIFICATION

COLOR BLACK AND WHITE

(A) [see photo map 2.2.2 (C)]

COLOR BLACK AND WHITE

(B) [see photo map 2.3 (C)]

FIGURE 42 COMPARISON OF COLOR AND BLACK AND WHITE PHOTOGRAPHY IN TERMS OF LAND FORM AND SOIL TYPES AND SOIL CONDITION DETERMINATION.

illustrates two soils readily distinguished on the basis of color (arrows 1 and 2, 4 and 5). The drainage feature at arrow 6 is more significant on the color photo than on the black and white. Arrow 7 shows the disturbed soil over a buried pipeline. It is a feature that is more striking on color and could be followed for a longer distance on color than on black and white.

Figure 41(b) is another example to show how color is a great asset in photo-interpretation of terrain. Arrow 1 indicates the borderline of two land forms and associated soils. Arrows 2 and 3 point to low sand dunes that were easier to delineate on the color because of the color contrast. Arrows 4, 5 and 6 show examples where it was possible to distinguish a condition of soil on the basis of color. On the black and white, it was not possible to determine whether the features were dark colored soils or were wet soils. The color photo indicates that 4 and 5 are similar and are darker brown and wet soils. Area 6 is a soil with higher organic content and it is also wet. Arrow 7 indicates ponded water which is not readily detected on the black and white.

Figure 42(a) is an example where dark soil (arrows 1, 5 and 6) can be readily delineated and differentiated from darker more organic soil (arrow 7) and from sub-surface drainage features (arrow 4). Areas containing thin silt in the A-horizon (arrow 2) can be located very precisely on color but not on black and white.

Figure 42(b) shows how color is of value in distinguishing muck (arrow 1) from dark colored soil (arrow 2), and to locate wet zones under a thin grass cover (arrows 3 and 6). Color shows the ponded water (arrow 4) while black and white does not.

3.26 Color Infrared Film for Engineering Soil Mapping

After the color photo-mosaics were interpreted, a very detailed and careful study was made of the color infrared film positives. The main advantages of this film over color and black and white is the fast and accurate location of vegetation. This advantage was not a great asset for soil mapping but it was extensively used in the computer analysis of the multispectral imagery (see Chapter 4) in the "training samples" selection phase.

Another advantage of this film type is to show the relative moisture conditions of the soils in a much better way than natural color. This is due to the fact that the film is sensitive to the near infrared band (0.7 to 0.9 micron) and water is a great absorber of energy in that band. A wet condition is detected on the film by darker hues of blue or blue-green.

The filter used with the color infrared film was a Wratten 12 according to the film maker's recommendation. The effect of the Wratten 12 filter, as compared to the Wratten 15, is a shift of the color toward the blue; the vegetation therefore is purple-red instead of red, the bare soil areas show in different hues of blue instead of green. The author compared his results with several rolls of infrared color film obtained for the Laboratory for Agricultural Remote Sensing (LARS), by a NASA aircraft. A Wratten 15 was used which gives a color shift to the green. The aging of the film is also critical.

The color infrared film was exposed approximately four weeks after the color photography. Even with this delay, the color and color infrared photography were evaluated and compared. The weather conditions over

the area were similar for the few days preceeding the exposure of both film types.

It was found that color infrared transparencies yield more information than color film or prints on soil surface drainage conditions, wet zones, and the like.

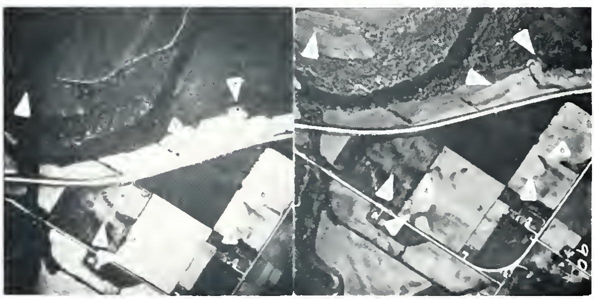
Of importance in the interpretation, it was found for the bare soil areas that the blue color darkened (increase in value for the blue hue) as the moisture increased; in other words, darker blue areas are more wet. This occurred independently of the soil type and the soil color, except that lighter soils had a tendency to be of a lighter blue to start with.

Muck pockets and high organic soils were not as easily detected and identified in comparison to color. Highly plastic red clays in the limestone plains were rendered in different hues of green and different values, depending on their reddishness and their moisture content. Taking the color balance shift into account, these clays would be expected to show in characteristic hues of greenish yellow to yellow for the light brown-red to the deep red clays respectively. Color and color infrared both were of equal value in the identification of red clays.

Figure 43(a) shows two reduced color photos corresponding to the original color infrared and color frames. Arrows 1 and 2 indicate that the color infrared film is poor at distinguishing two types of soils having similar moisture conditions. But arrows 5 and 6 points out the great efficiency of color infrared to detect a moisture condition either of bare soil (arrow 5) or through a thin vegetative cover (arrow 6). Arrow 3 shows the soil boundary that was indicated by arrow 1 as continuing under the thin vegetation cover. Arrow 4 indicates stubble ground.

COLOR INFRARED COLOR

(A) [see photo-map 1.1]



COLOR INFRARED COLOR

(B) [see photo-map 2.2.1(C)]

FIGURE 43. COMPARISON OF COLOR INFRARED AND COLOR PHOTOGRAPHY IN TERMS OF SOIL MOISTURE CONDITIONS.

In a similar manner, Figure 43(b) shows that moisture distribution in the soils can be detected most readily on the infrared color film; refer to arrows 6 versus arrows 4 and 5. Note that at arrow 4 the accumulation of moisture has been modified at the field boundary.

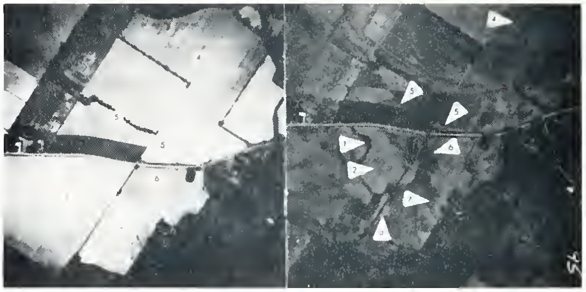
Figure 44(a) is also an example of how color infrared film records moist areas: refer to arrows 5 and 7. Figure 44(b) indicates a condition of highly organic, wet, clayey soil. Arrows 1, 2 and 5 indicate the range in wetness of the area as recorded on infrared film, and the high organic content shown by dark colors on the color photo. Arrow 4 indicates ponded water more readily detected on color infrared film than on color, but also detected on color.

3.27 Black and White Infrared as a Film For Mapping Soils

Black and white infrared film was evaluated in this study. It was found to have some of the color infrared film advantages. It emphasizes the vegetation (light tones) and water bodies (dark tones). It permits to detect moist zones in the bare soil areas but not as accurately as color infrared does. It was found to be very poor for delineating soil boundaries: very little and often no contrast at all occurred. For this reason, the black and white infrared was not used in this study for engineering soil mapping. Filtering by the Wratten 12 was inadequate.

3.28 Accuracy of Engineering Soil Mapping

Engineering soil mapping has always been subject to the question of accuracy. This is a delicate point. Accuracy is a very relative term which supposes the existence of some standard to gauge the accuracy on some point or another.



COLOR INFRARED COLOR

(A) [see photo map 2.2.2 (C)]

COLOR INFRARED COLOR

(B) [see photo map 2.3 (C)]

FIGURE 44 COMPARISON OF COLOR INFRARED AND COLOR PHOTOGRAPHY IN TERMS OF SOIL MOISTURE CONDITIONS.

The role of engineering soil maps was explained in Chapter 1. Engineering soil maps in general are accurate in determining and locating engineering soil classes on a broad textural basis. They are accurate in delineating land forms and therefore parent-materials related to land forms. The accuracy is limited by factors such as the scale (both photo scale and final map scale), the amount of field correlation, the experience and ability of the photo-interpreter and the type of film used to obtain the information.

This study indicates that the best film for mapping of engineering soils is color. The recommended scale for detailed engineering soil mapping is 1:12,000. It is the most convenient for both interpretation and field work. If the mapping is to be reported on plans and profiles, the photo scale should be compatible with the plan and profile scale used in the project and should not be smaller than 1:6,000. A scale of 1:4,800 is recommended.

The amount of soil sampling in the field cannot be fixed in advance; it depends entirely on the interpreter's experience with the area, his experience as a photo-interpreter in general and the type of terrain. A starting point could be three field check points for each type of land form or each conspicuous soil condition. This number can be reduced or augmented as a better understanding of the area is acquired.

3.29 A Quantitative Approach to Color Interpretation

In the first phase of this project, Rib developed a method of color coding [87, 211] which was used in this study for designating the colors of a color print. A color photo was used (frame 56, shown on Figure 43(a)) and the photo was divided into 1/2-inch square grids. The color

density readings were taken for each grid point with the visible, blue, green and red filters on a reflection densitometer with a 3 mm aperture, as was used in Rib's study.

Two hundred and twenty one points were measured and color coded, following the method indicated. The color coding was successful when comparing the points on the photo with the Munsell Book of Color. The result is a three dimensional numerical figure, representing the hue-value-chroma. The method was found to be of little practical value in terms of automatic color interpretation at this stage and the time for measurement of density values and computation was beyond practical time limits. The study was abandoned.

3.3 Summary of Results

During this study on engineering soil mapping from different sources of data, five maps as line drawings and 28 photo-maps were developed.

It was found that the geological data obtained from detailed geological quadrangle sheets is insufficient as a unique source for engineering soil mapping. It was found that pedological data assisted by engineering literature on pedological significance is a valid approach but is not sufficiently representative of the soils and terrain conditions to be useful as a unique source of data for detailed engineering soil mapping.

Of the 28 photo-maps, five were at a small scale (1:20,000) and covered a total area of 350 sq. mi. This type of information appeared to be necessary for developing detailed engineering soil mapping.

Of the remaining 23 photo-maps, nine were at an intermediate scale of 1:12,000 for a total area of 134 sq. mi. The others were at 1:4,800

scale and five of these were developed by interpretation of color aerial photographs. Infrared color and black and white infrared films were also studied. It was found that color is the best single source of information for engineering soil mapping. The best combination of two films is color and color infrared. This combination enables, in all cases met in this study, the determination of the moisture conditions of the soils and the intrinsic color of the soils. None of these two films can do this by itself, for all cases. The black and white infrared film was of little value for engineering soils mapping, with the filtering that was used.

The optimum scale was found to be 1:12,000 when the interpretation is not to be reported on standard engineering plans and profiles. If reported on plans and profiles the optimum scale was found to be at least 1:6,000, or as large as 1:2,400, depending on the scale used for the plans and profiles of the given project.

Time of interpretation was found to increase very much with an increase of the photo scale. The use of color was found to decrease the time of interpretation from 20 to 40%, at a scale of 1:4,800.

CHAPTER 4

MULTISPECTRAL IMAGERY AS A SOURCE FOR ENGINEERING SOIL MAPPING

As recommended in the first phase, multispectral imagery was obtained by contract from the University of Michigan. The study route from Indianapolis to Bedford was covered in two single flight lines; one north to south at an altitude of 3200 feet, the second south to north at an altitude of 1600 feet. The imagery was obtained in fifteen different bands of the electromagnetic spectrum as listed on Table 6.

4.1 Scope

This chapter covers the interpretation of the multispectral imagery by three different techniques (1) by visual examination, (2) by densitometry on the negatives, (3) by the automatic computer classification of spectral signatures, as developed by the Purdue University Laboratory for Agricultural Remote Sensing (LARS).

The spectral reflectance of the characteristic materials of the study area was investigated in the laboratory. Field thermal measurements were conducted and an attempt to statistically evaluate field variables on thermal radiance was performed.

4.2 Method of Study

A total of seven days were used to collect field data on soil temperatures, most particularly with a Barnes PRT-4 portable radiometer

TABLE 6

SPECTRAL BANDS FOR IMAGERY OF INDIANA PROJECT
AS COLLECTED BY PROJECT MICHIGAN SCANNER

RANGE	BAND NUMBER	SPECTRAL BANDWIDTH
ultraviolet	-	0.32-0.40 micron
visible (violet)	1	0.40-0.44
visible (blue)	2	0.44-0.46
visible	3	0.46-0.48
visible (blue-green)	4	0.48-0.50
visible	5	0.50-0.52
visible (green)	6	0.52-0.55
visible	7	0.55-0.58
visible (yellow)	8	0.58-0.62
visible (red)	9	0.62-0.66
visible (red)	10	0.66-0.72
near infrared*	11	0.72-0.80
near infrared	12	0.80-1.00
middle infrared	-	4.50-5.50
far infrared	-	8.00-14.00

*The near infrared up to approximately 1.5 micron is also called reflective infrared. See Figure 9 for the other arbitrary divisions of the infrared.

measuring the thermal radiance of soils, in the 8-14 micron region. These readings were studied in combination with glass thermometer temperatures and moisture content of the surface soils. This investigation was the object of a statistical analysis and the results are reported.

The results of the field temperature study indicated the need for knowing more about the cyclic heat history of different soils. For this reason, a 24-hour period of repeated radiometer and glass thermometer readings was undertaken on August 12, 1967. Although of value, these results were considered incomplete and a second experiment was conducted, this time with the improved Barnes PRT-5 radiation thermometer*. Instead of traveling from station to station to take the readings, a set of twelve 18"x18"x8" wooden boxes containing the representative soils studied in August were laid outside the Purdue University Civil Engineering building. Radiometer readings, glass thermometer temperatures and moisture contents were measured every thirty minutes for a period of 48 hours. These measurements took place on September 6 and 7, 1968. The results are presented and discussed in a later section.

It was stated in a previous section, that multispectral remote sensing is based on the premise that materials reflect and emit energy each in their own way and that study of the reflectance and emittance properties of materials would result in "spectral signatures" characteristic of each material or each class of similar materials. Spectral signature as used here may not necessarily be a unique signature for each specific material.

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*Brand names of instruments are indicated only to inform the reader of the specific instruments used in this study and do not imply indorsement or lack thereof of this or any other similar type of instrumentation.

In order to study the reflectance properties of the typical materials of the study area, samples of soils and rocks were selected and their spectral reflectance curves were developed using a Beckman DK-2A reflectance spectrophotometer. The results are reported.

4.3 Laboratory Reflectance Measurements

The special study on reflectance had several purposes: (1) to determine if the soils of the study area had characteristic spectral reflectance signatures, (2) to determine how much variation occurred and (3) to determine what factors influenced the reflectance.

The samples used were of three types: (1) soil clods shaped with a spatula to fit the reflectance spectrometer sample holder, keeping at least three faces of the samples with natural rough surface, (2) rock specimens of the characteristic rock formation of the area, namely the Borden siltstone (weathered and unweathered), the Salem limestone and the Harrodsburg limestone, having at least three natural rough surfaces and three surfaces ground flat with standard 80 mesh grit, and (3) samples of the soils used in (1) but having controlled moisture content and mounted in special glass sample holders.

The Beckman DK-2A reflectance spectrometer is a double beam ratio recording spectrophotometer. The radiant energies reflected by the reference and the sample beams are compared and the ratio of the sample energy to the reference energy is recorded as a percent reflectance. Calibration for 100 percent reflectance is made by using two similar magnesium oxide reference samples. The instrument uses an integrating sphere coated with magnesium oxide (MgO) and sums up the energy reflected in all directions. Two positions are possible on the instrument to

measure the total reflectance and diffuse reflectance. In this study, the total reflectance was measured.

Figure 45 shows the results of reflectance of the soil samples (clods) in the range of 500 to 2500 millimicrons (the region 2500 to 2700 millimicrons should be neglected because of the fall-off of the calibration curve as it is limited by the detector response range; see standard curve on Figure 47-C). The numbers in the legend like 1, 13, 15 indicate the sample number (see data and sample numbers in Appendix 1). The letters refer to separate samples of a given soil; like 13a, 13b, 13c are three separate specimens of soil sample 13.

The other sample characteristics are explained on Figure 45. Note that each curve is the average of three measurements. The numbers in parenthesis near each curve refer to the moisture contents. Note the water absorption bands at 1900, 2300 and 2500 millimicrons.

These curves indicate the following results:

1) for a low plasticity clayey silt (CL-ML) the reflectance is not much affected by the surface texture except if it becomes very rough (Figure 45-A)
2) for higher plasticity silts and clays, the reflectance is more affected by the surface texture and the higher reflectance occurs for the smoother surface (Figure 45-B and C)
3) for very high plasticity red clays (CH) the reflectance drops substantially at all wavelengths (Figure 45-D); this is partly explained by the higher moisture content.
4) for all soil samples, moisture content is a major factor affecting reflectance; the higher the moisture content the lower the

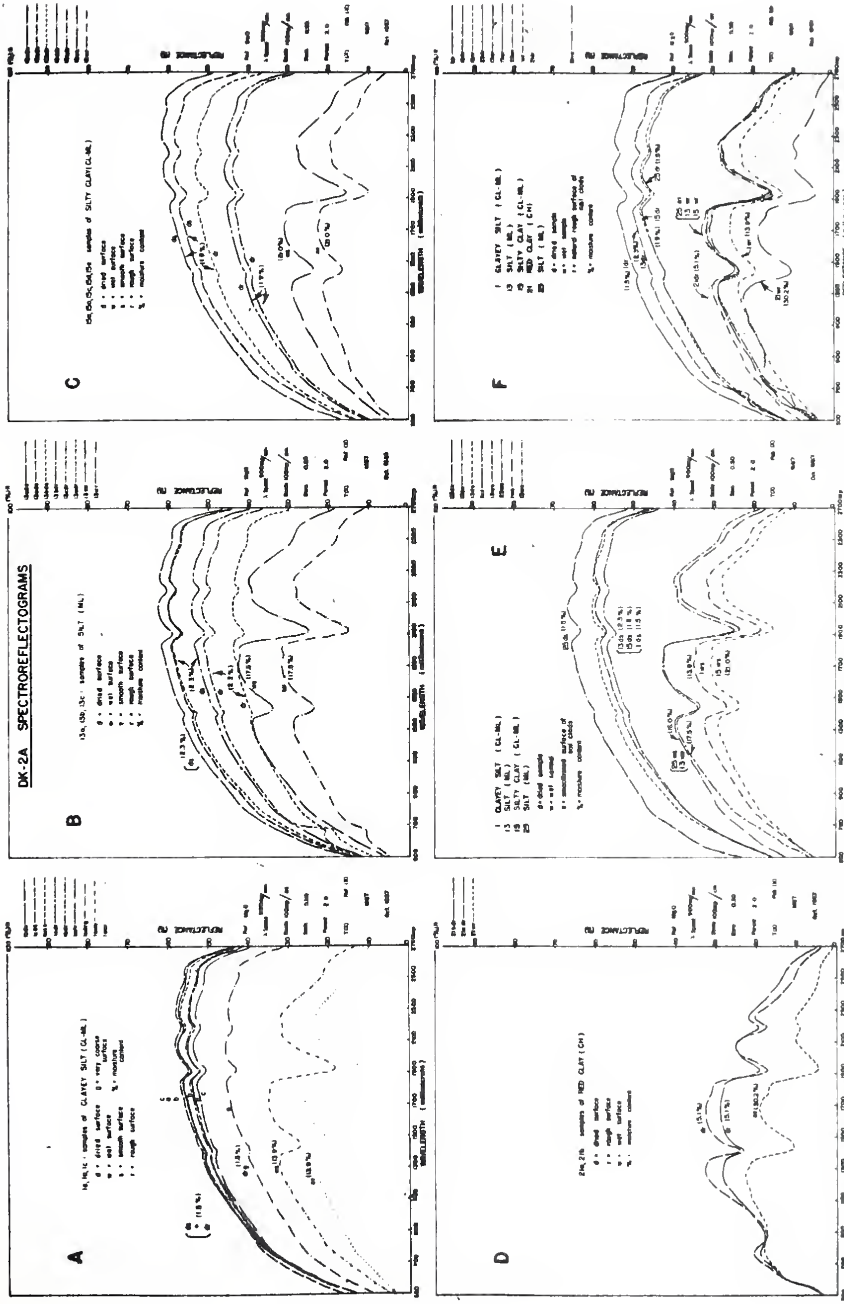


FIGURE 45 LABORATORY SPECTRAL REFLECTANCE OF SOIL SAMPLES

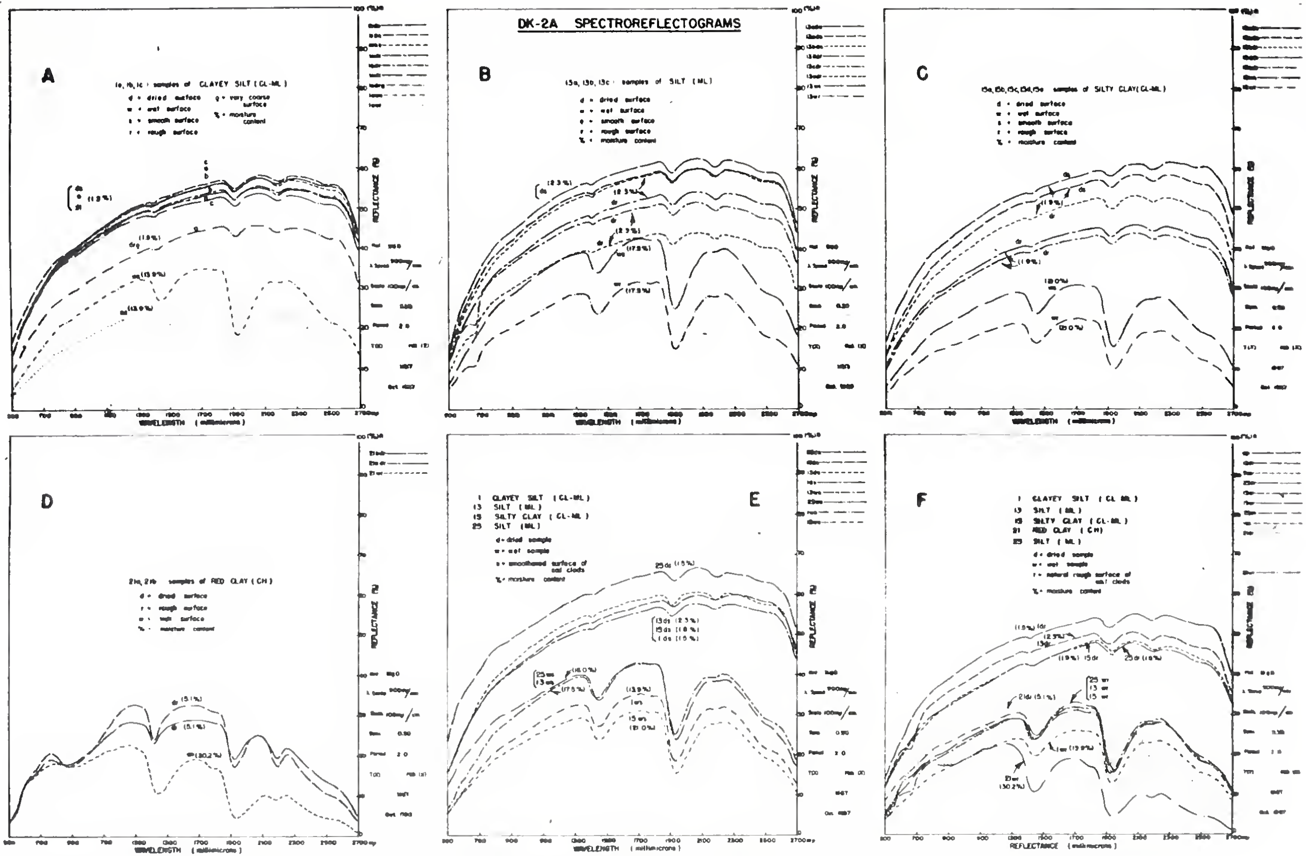


FIGURE 45 LABORATORY SPECTRAL REFLECTANCE OF SOIL SAMPLES

reflectance at all wavelengths. The moisture content appears to be a more important factor on reflectance than surface texture.

5) for the range of wavelengths investigated, there is very strong indication that each soil or soil class does have a reflectance curve of its own and it appears to be correct to speak of spectral signature, but the moisture content does complicate the situation. Further study is required, using statistical procedures and very accurate control of moisture, in order to determine soil signatures under various moisture contents.

Figure 46 shows the results of reflectance of rock samples again in the range 500 to 2500 millimicrons. The type of rock is indicated by the first two digits and the specimen number is given by the number after the decimal point. Letters indicate the surface and moisture conditions. From these curves the following is concluded:

1) for the siltstone specimens, the smooth surfaces (using #80 polishing abrasive) show a higher reflectance than rough surfaces (Figure 46-A, B)
2) for the siltstone specimens, the degree of weathering very highly affects the reflectance; in Figure 46-B specimens 4 and 5 were weathered to a darker brown and specimens 1 and 2 (light yellow brown) were less weathered. Thus, as the degree of weathering increases, it appears that the reflectance decreases,
3) for the limestone specimens used the surface texture did not appreciably affect the overall reflectance,

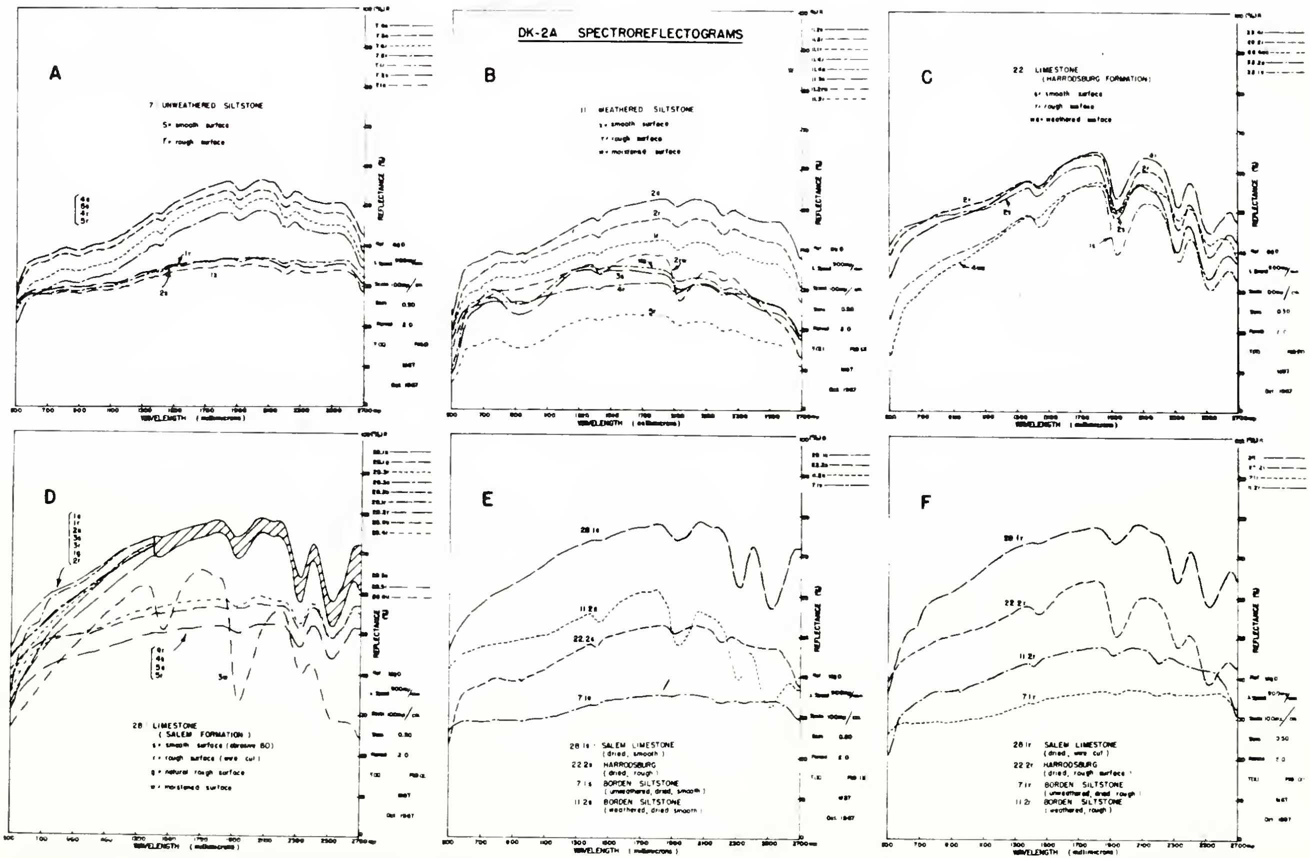


FIGURE 46 LABORATORY SPECTRAL REFLECTANCE OF ROCK SPECIMENS

4) moistening of the surface of the specimens did substantially decrease the reflectance for all the siltstone and limestone specimens.

Figure 47 shows the reflectance curves obtained for soils at controlled moisture contents. To a given weight of soil, a measured volume of water was added to obtain the moisture contents of 5, 10, 15, 20 and 30 percent. The samples were covered and stored overnight to allow for more uniform moisture distribution. The reflectance curves were then obtained and the moisture content was determined by the oven method. The actual moisture contents measured appear in parenthesis on the respective curves.

The curves of Figure 47 show a consistent decrease of reflectance with an increase of moisture. The decrease in reflectance seems to reach a threshold at around 20-30 percent moisture, as can be inferred from the decrease spacing between the reflectance curves (see Figure 47A, C, D and F). The curves for 20 percent and 30 percent moisture at F are reversed. This also occurs at D and also at A. This is unexplained but a tentative opinion is that as the water fills the pores, the reflectance measured is composed of two reflectances; one for the soil grains, one for water. It so happens that at a given moisture content (probably a function of grain size distribution, pore size, pore spacing and minerals present) the reflectance for water becomes the major component and the total reflectance starts to increase again. On these premises, further research is justified.

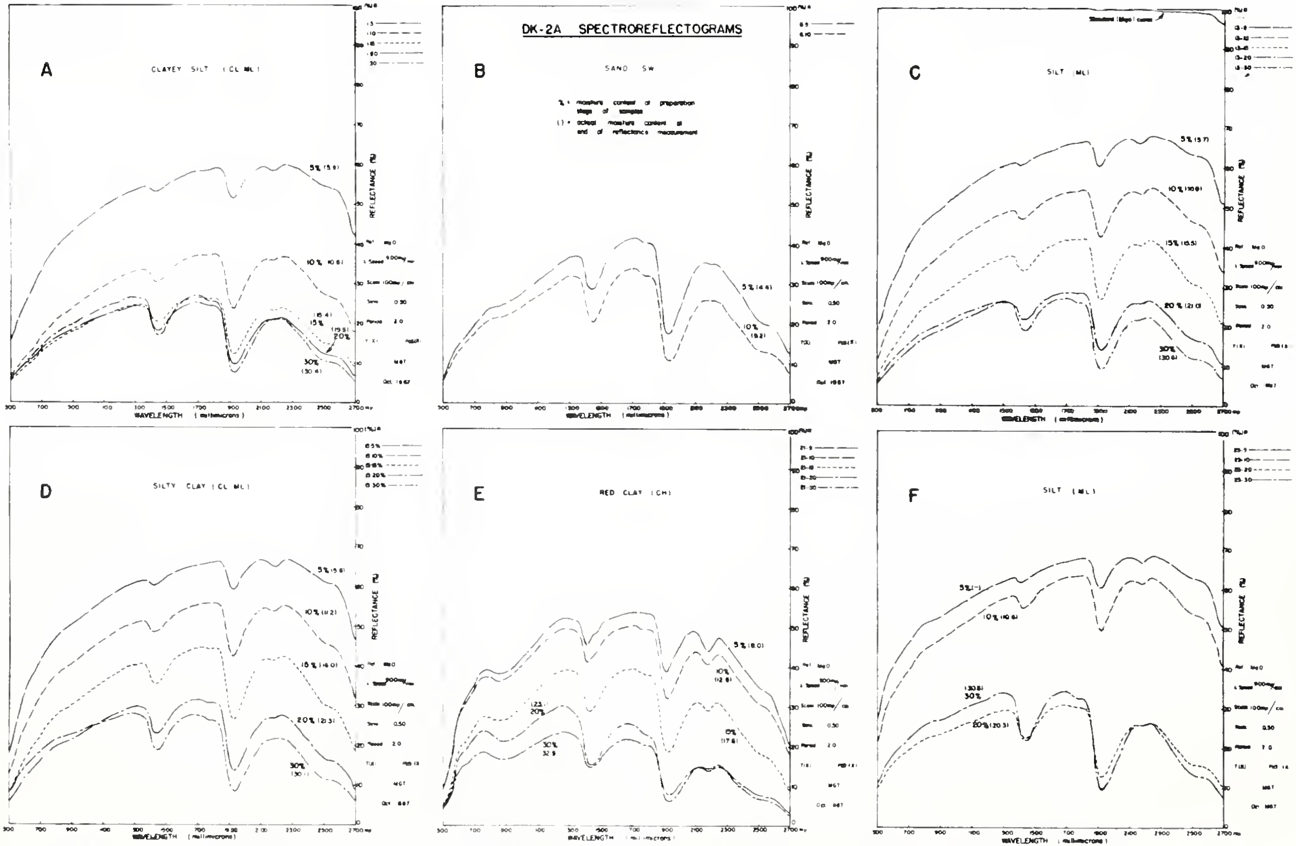


FIGURE 47 MOISTURE AS A PRIMARY CONTROLLING FACTOR ON REFLECTANCE

4.4 Statistical Analysis of Some Field Variables on Infrared Radiation

Previous to and following the day the multichannel imagery was obtained, field information, generally referred to as "ground truth," was gathered on the soil and rock temperatures and other factors that influence the infrared radiation.

For this purpose a Barnes PRT-4 portable radiation thermometer was used. The Barnes portable radiometer is a thermistor bolometer type of instrument which measures the apparent temperature in the 8-14 micron region. The active element in the thermistor bolometer is a thin semi-conductor film which operates by virtue of resistance change produced by the incident radiation. A normal bolometer bridge circuit includes two identical thermistor elements mounted on the same base for compensation of changes in ambient temperature; one is the active element and is exposed to radiation, the other is shielded.

A total of 28 different test sites (also called stations in this report and on some of the figures) were selected. They were selected as a set of representative areas of the characteristic soils for the study route and had to meet certain requirements such as accessibility, flatness and clearness, availability during the whole study period, and uniformity of the material. These sites are further described in Appendix 2.

On each test site, radiometer readings were taken, as well as glass thermometer temperature readings, at one half and four inch depths for soil and at the surface for the rock test sites. The purpose was to study the validity of using the glass thermometer as compared to the radiometer readings to measure surface temperatures and also to study

the influencing factors.

The original idea was to use several portable radiometers but problems of availability of such instruments hampered the experiment quite seriously. It was thought that by using several glass thermometers and by spot-checking with the radiometer, it would be possible to obtain sufficient field information on ground temperature variations, for comparison with the thermal infrared (8-14 micron region) imagery.

Another problem was the poor accessibility to the study area. Each time the investigator wanted to reach the study grounds, a distance of 60 miles had to be travelled to the northern end of the study strip which then extended 70 miles further south. Thus, each day of field data collection included a bare minimum of 200 miles of travelling, plus of course, travelling back and forth between the test sites, if more than one set of readings were to be collected. The problem of inaccessibility of the study area was considered to be a major one.

In addition to the radiometer readings and glass thermometer temperatures, samples for moisture content were collected, and all available ground conditions such as wind conditions and estimated percentage of cloud cover were gathered.

Numerous plots and graphs were prepared based on this data and major trends were evaluated. For this purpose, the radiometer readings or apparent temperatures were first compared to the glass thermometer temperatures and then moisture changes were studied as a function of apparent temperatures (radiometer readings).

From the basic radiation laws and particularly from Stefan-Boltzmann law, $W = \epsilon\sigma T^4$ (equation 2.5), there is a direct relationship between the

temperature T and the energy radiated W. Assuming that the radiometer is correctly calibrated, there should be for a given emissivity a direct relationship between the temperature of the scene filling the field of view (or the resolution patch) and the apparent temperature read on the instrument. Without entering the domain of infrared radiometers design it can be said that the detector in a radiometer measures the difference ΔW between the source radiation energy focused on the detector and the radiant energy reference level inside the radiometer. This is expressed by

$$\Delta W = W_s - W_r \tag{4.1}$$

where W_s is the source energy upon the detector and W_r is the radiant energy reference level or internal radiometer calibration reference. The voltage output of the detector is proportional to ΔW according to

$$\Delta V = R\Delta W \tag{4.2}$$

where ΔV is the voltage produced by ΔW and R is the "responsivity" of the detector, which defines the voltage output from the detector for each radiant energy unit focused upon it.

With these basic considerations in mind, it can be suspected that if glass thermometers actually measure the scene temperature properly, there should be a direct relationship between glass thermometer temperatures and apparent temperatures as measured by the radiometer. In other words, the values for a given material should plot linearly on a 45 degree line and if they do not, then the theoretical consideration is still valid but factors affecting measurements ought to be the object of further considerations and studies.

This is precisely what happens when plotting the radiometer apparent

temperatures against the temperature of soils and rocks. Figures 48 to 53 are reproduced to illustrate this point.

The radiometer readings were taken by holding the radiometer head at a 45 degree angle and pointing successively in the four directions--north, east, south and west, as indicated on each of the graphs of Figures 48 to 52. At the same time, two glass thermometer readings were taken; one for a thermometer buried at one-half inch in the soil, the second buried at four inches with the stem sticking out of the ground. For the rock outcrops, the glass thermometer was laid in contact with the rock surface.

Figure 48 illustrates the results for the four different directions of reading the radiometer measurements for a silt loam at test sites 1 to 5. On each graph, an equation for the line of best fit by the least square method was computed. These graphs were obtained from a Weighed Regression Analysis Program (WRAP) for computing the linear regression equation, the correlation coefficient (R) and the standard error (STD. ERR.) for the b_o term. The plotting was executed with the aid of a computer program called PLOT, assembled by A. K. Turner, Civil Engineering, Purdue University, which consisted of assembling subroutines provided by CALCOMP and developed for the CALCOMP model 563 digital incremental plotter.

On these graphs, a linear regression equation of the first degree is given for each set of data. The general form is

$$Y = b_1 x + b_o \tag{4.3}$$

where the y-term is replaced by the radiometer readings (RR) (units are in micro-watts per square centimeter) and the x-term is replaced by (T)

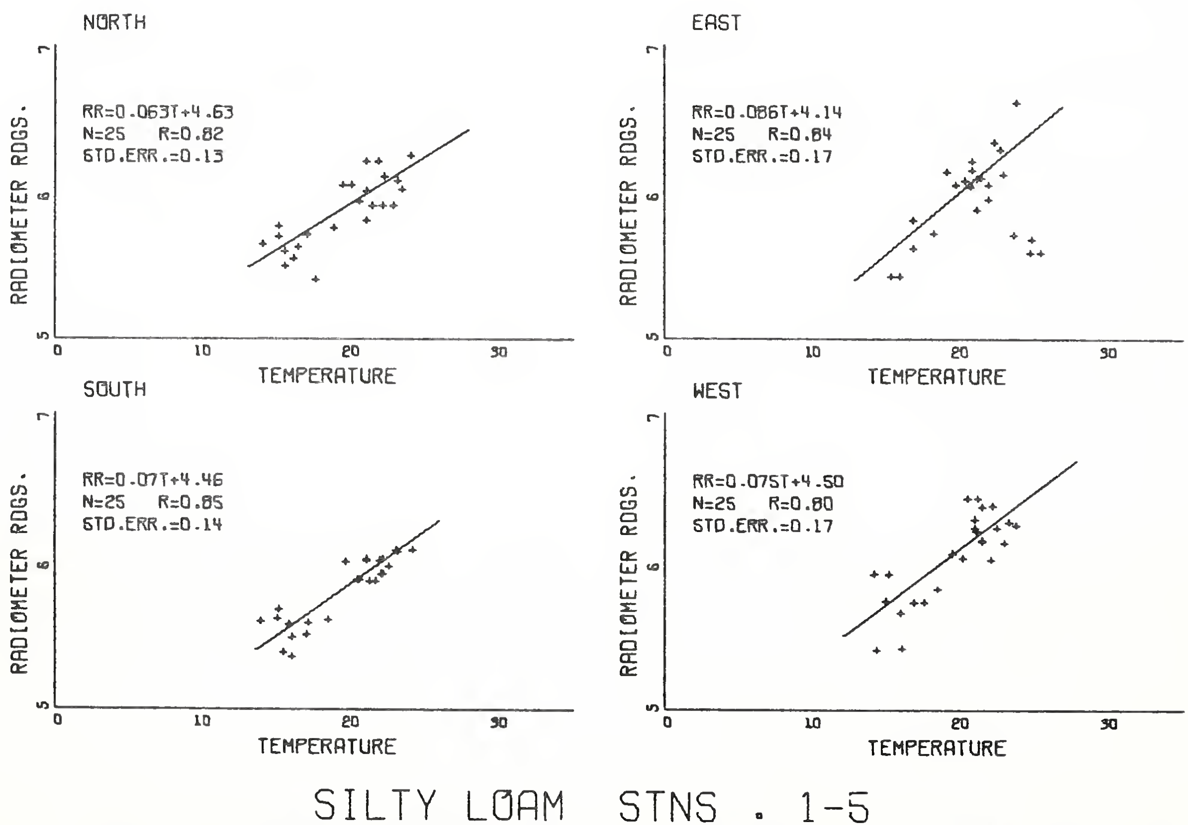
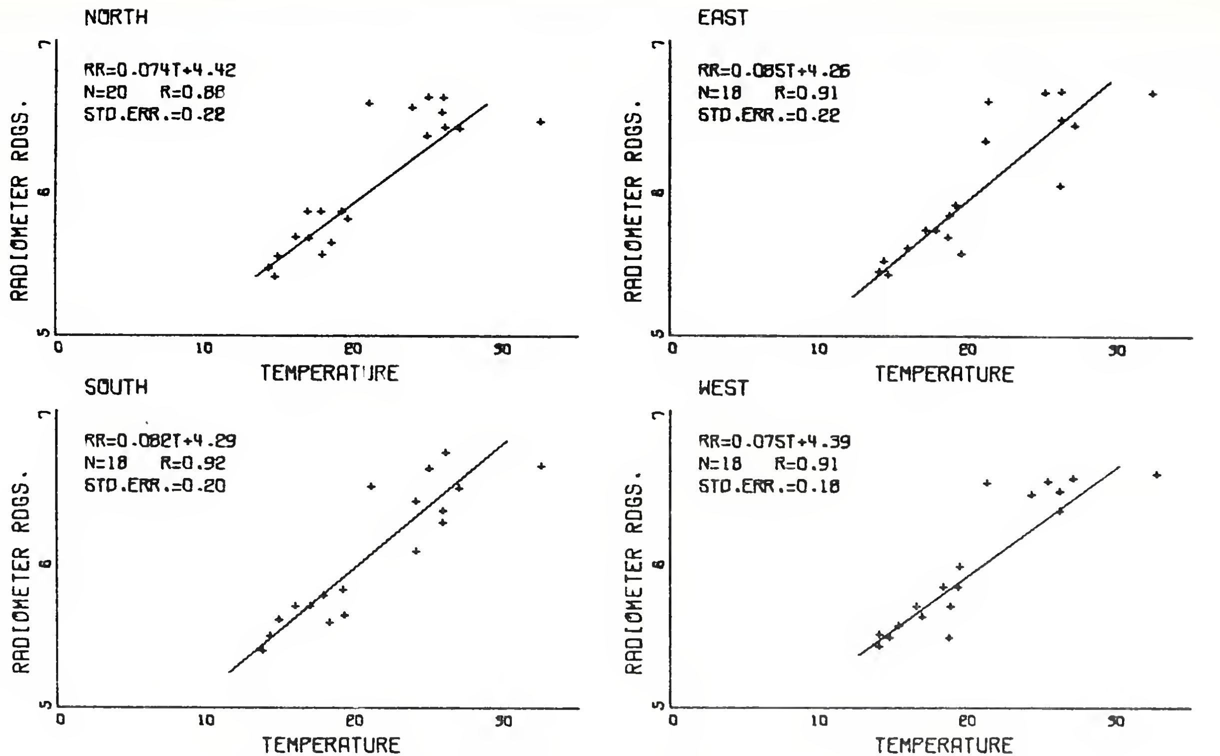
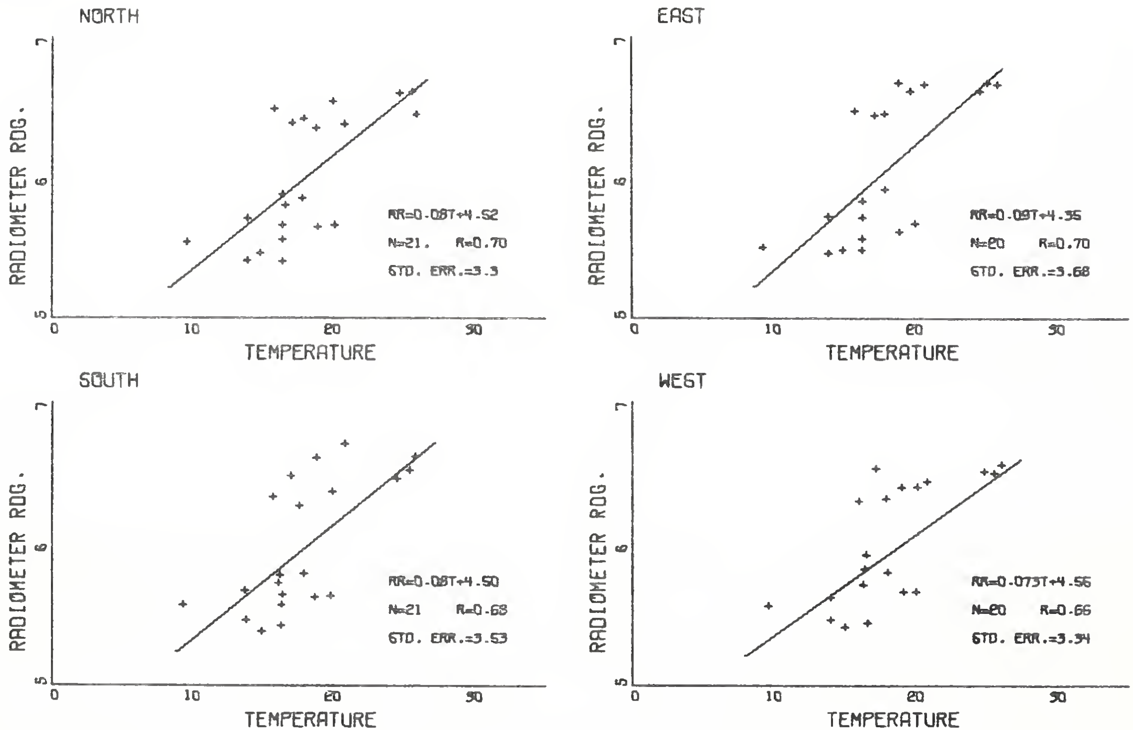


FIGURE 48. APPARENT TEMPERATURE AS A FUNCTION OF TEMPERATURE AT DEPTH OF A HALF INCH FOR SILTY LOAM AT TEST SITES 1 TO 5



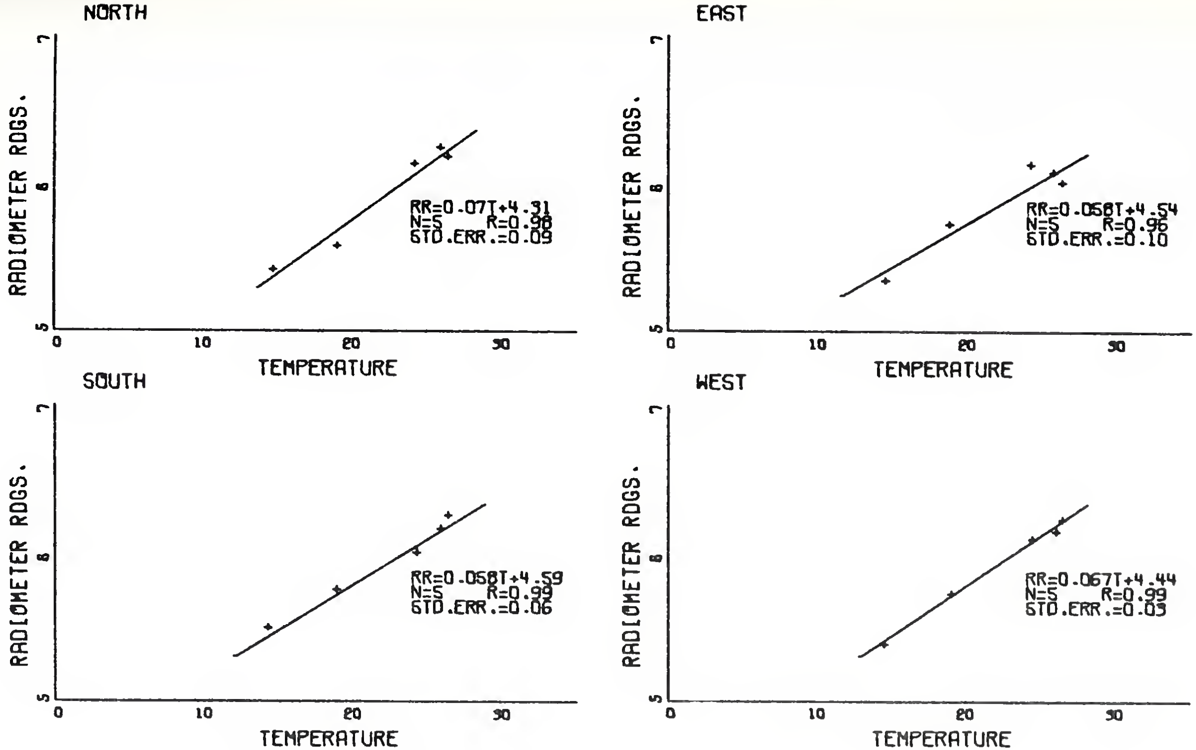
CLAY (TERRA RØSA) STNS 19,20,21,24

FIGURE 49. APPARENT TEMPERATURE AS A FUNCTION OF TEMPERATURE AT DEPTH OF A HALF INCH FOR RED CLAY



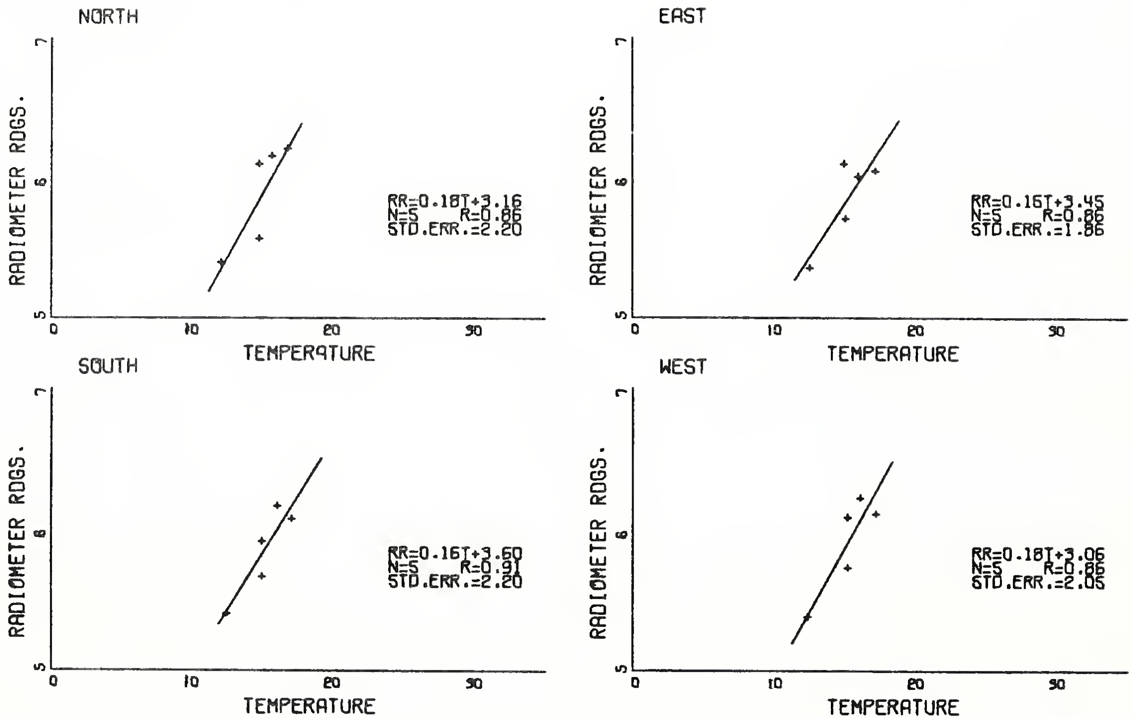
CLAY (TERRA RØSA) - STNS. 19-21,24

FIGURE 50. APPARENT TEMPERATURE AS A FUNCTION OF TEMPERATURE AT DEPTH OF FOUR INCHES FOR RED CLAY



SILT STNS. 25,26

FIGURE 51. APPARENT TEMPERATURE AS A FUNCTION OF TEMPERATURE AT DEPTH OF A HALF INCH FOR SILT



SILT STNS. 25,26

FIGURE 52. APPARENT TEMPERATURE AS A FUNCTION OF TEMPERATURE AT DEPTH OF FOUR INCHES FOR SILT

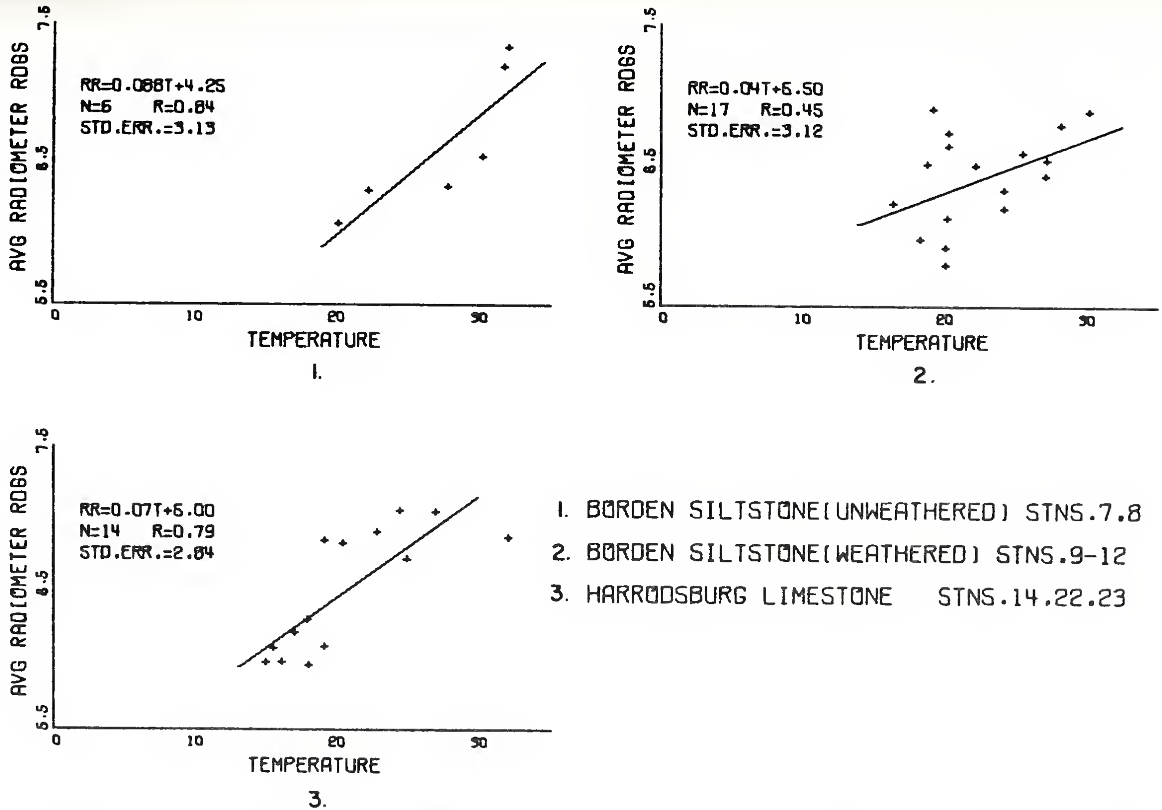


FIGURE 53. APPARENT TEMPERATURE AS A FUNCTION OF TEMPERATURE OF ROCK SURFACE FOR THREE ROCK TYPES

for the glass thermometer temperature in degrees Celtius. (N) represents the number of measurements.

Figure 48 indicates a fairly large spread of the data points. One would expect a set of points close if not on line, according to the premise previously mentioned. It also shows that the data points appear in clusters, indicating that different overall conditions prevailed between the sets of readings. Figures 49 and 50 indicate somewhat similar results for red clay, with a wider range of variability for glass thermometer values measured at a four inch depth. By superposition of these two figures one would find the average temperature lag between the one-half inch depth and the four inch depth readings.

Figures 51 and 52 indicate similar results except that the four inch depth readings, as indicated by the steeper slope of curves on Figure 52, denote a different rate of change in the soil temperatures: in other words the glass thermometer values varied on a much narrower range for the silt than for the clay (see Figure 50). On closer examination of the field data, it was found that the water table was very high (near the surface) for test sites 25 and 26, which explains the different slope.

Figure 53 illustrates the results obtained for three types of rocks. These curves indicate a different behavior for rocks than for soils and greater temperatures for the weathered Borden siltstone (brown) than for the unweathered siltstone (gray) and the limestone (white).

From these measurements and other field information one could summarize the field results as follows:

1. The direction of radiometer readings did not change the results appreciably, indicating a Lambertian surface for the materials

studied. Thus any direction is valid and can be used in other experiments, as long as the ground surface is level or is very close to level.

2. The effect of wind was found to be critical on the radiometer readings: all sites showed the same apparent temperature on days of high wind velocities. A value of 10 mph is indicated above which apparent temperature measurements are not usable.
3. The moisture content of soils varied as an inverse function with the apparent temperature and appeared to be a most important factor on the temperature.
4. The use of a radiometer is not as simple as it may seem; the readings can be affected by small changes in surface texture due to plowing practice, size of surface soil clods, presence of minor amounts of green vegetation on a supposedly clean bare soil target area. These factors affect the readings in that they tend to lower the average apparent temperature of the target filling the field of view, due to shadows created, or due to small spots of higher moisture content.
5. The clustering of the data points also indicates the importance of the environmental conditions. The soil moisture, the wind velocity, the time of day, the amount of dew and the previous weather and precipitation over the site principally affect the results.

In an attempt to correlate some of these field conditions between each other, a multiple linear correlation and regression analysis was used in which the field data was used as the input. The approach was

intended to indicate trends only and not to procure a model of soil radiation behavior because it was known ahead of time that the field information was too fragmental. The principal purpose was to investigate among the variables measured which factors seemed to influence the average radiometer readings, in what sequential order of importance.

The Purdue University IBM 7094 electronic computer was used for these calculations and the BIMD-2R, Stepwise Regression Analysis computer program prepared by the Health Sciences Computing Facility at the University of California at Los Angeles was utilized to obtain the correlation coefficients between the variables.

The variables considered are listed on Table 7. The average radiometer reading was the dependent variable. All variables are self explanatory except for the grain size factor (GSF) and the soil texture factor (TEXT). These were based on field data collected at the time of the experiment. The GSF factor was scaled 1 to 10 for clay soils to gravels respectively and intermediate soils were given intermediate values. The TEXT factor was also scaled 1 to 10 to represent very flat, smooth, uniform surfaces to rough, bumpy surface and/or rough plowing with deep furrows; again intermediate terms were given intermediate values. Although this approach may not seem highly rigorous as it is based on an estimation, it is sufficiently accurate to indicate trends.

The correlation coefficients are given on Table 8, in a correlation matrix form. From this correlation matrix, simple correlation coefficients were obtained. Figures 54 and 55 are cluster diagrams as devised by Krumbein and Imbrie [120] to show the relation between the correlation coefficients for given sets of variables. Figure 54 indicates

TABLE 7

LIST OF VARIABLES USED IN THE CORRELATION COEFFICIENT STUDY

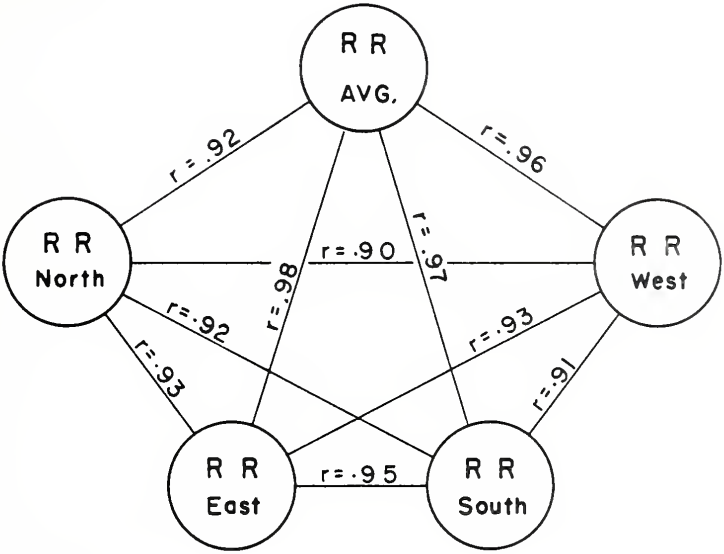
Variable No.	Description	Abbreviated Form
1	average radiometer reading of all four directions.*	$RR_{avg.}$
2	radiometer reading facing North	RR_n
3	radiometer reading facing East	RR_e
4	radiometer reading facing South	RR_s
5	radiometer reading facing West	RR_w
6	soil temperature at $\frac{1}{2}$-inch depth	$T\frac{1}{2}''$
7	soil temperature at 4-inch depth	T4"
8	soil moisture at $\frac{1}{2}$-inch depth	$W\frac{1}{2}''$
9	soil moisture at 4-inch depth	W4"
10	grain size factor	GSF
11	soil texture factor	TEXT

*For each reading, the radiometer head was held at a 45 degree angle, at a distance of 5 feet from the ground and aimed at the same patch of ground, from each direction--north, east, south and west.

TABLE 8

CORRELATION COEFFICIENT MATRIX

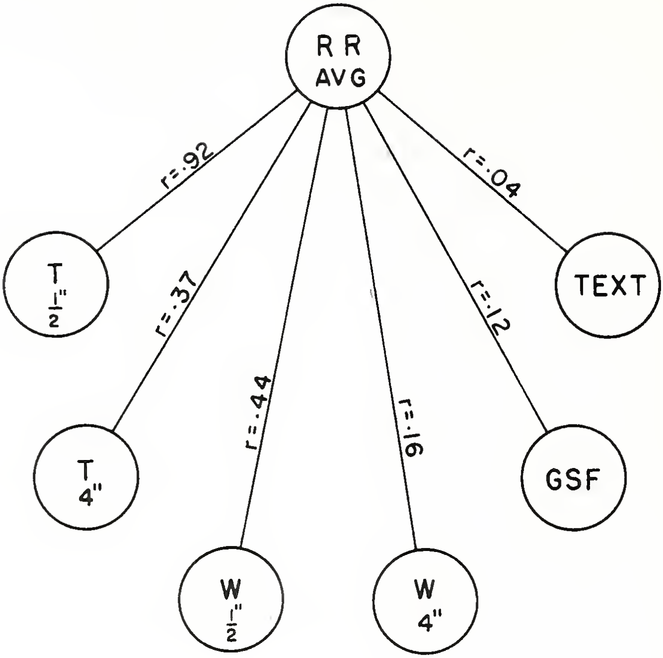
Variable Number	1	2	3	4	5	6	7	8	9	10	11
1	1.00	0.96	0.98	0.97	0.96	0.92	0.37	-0.44	-0.16	0.12	0.04
2		1.00	0.93	0.92	0.90	0.90	0.31	-0.47	-0.07	0.05	0.17
3			1.00	0.95	0.93	0.90	0.38	-0.42	-0.16	0.12	0.01
4				1.00	0.91	0.88	0.43	-0.40	-0.16	0.14	-0.02
5					1.00	0.88	0.30	-0.44	-0.24	0.17	0.02
6						1.00	0.38	-0.38	-0.05	0.02	0.19
7							1.00	0.14	0.14	-0.28	-0.38
8								1.00	0.35	-0.35	-0.17
9									1.00	-0.73	0.35
10										1.00	-0.73
11											1.00



RR AVG.: Average of radiometer readings as read pointing towards the four directions North, South, East, or West.

r: correlation coefficient

FIGURE 54. CLUSTER DIAGRAM OF SIMPLE CORRELATION COEFFICIENTS FOR THE FOUR DIRECTIONS OF RADIOMETER READINGS ON SOILS TARGETS.



RR AVG	:	Average radiometer reading
$T_{\frac{1}{2}"}$	:	Glass thermometer temperature taken at 1/2" depth
$T_{4"}$	:	Glass thermometer temperature taken at 4" depth
$W_{\frac{1}{2}"}$	:	Soil moisture content at 1/2" depth
$W_{4"}$	:	Soil moisture content at 4" depth
GSF	:	Grain size factor
TEXT	:	Soil texture
r	:	Correlation coefficient

FIGURE 55 CLUSTER DIAGRAM OF SIMPLE CORRELATION COEFFICIENTS FOR DIFFERENT FACTORS INFLUENCING THE APPARENT TEMPERATURE

very high correlation between the radiometer readings for the four directions within and among themselves and of course with the average. From these results it appears that there is no preferential direction and that any direction for all practical purposes is valid, as long as the surface being measured is flat. For practical reasons and for reproducibility, the same direction should be used at all times. It should be noted that this investigation took into account the geographic directions north-south-east-west only and it did not consider what would be the outcome if directions like 'facing the sun,' 'away from the sun' and the directions perpendicular to these two were to be considered. The whole problem at stake is polarization and surface texture effects. It is suspected that infrared radiometer measurements alone may not be able to solve this problem, but a polarimeter or a polarized radiometer could possibly yield more indicative results.

Figure 55 is a cluster diagram for the correlation coefficients of the other variables. This figure indicates a very high correlation of the average radiometer reading with temperature at ½-inch depth. It indicates a high negative correlation with the moisture content at ½-inch depth. The other variables are shown to be nearly insignificant, but this approach may not show all of the subtleties involved.

These data show that ground data must be collected at the time imagery is obtained and, ideally, for the few days previous to the flight mission. It assists in evaluating the soil conditions and radiation behavior. It proved the major influence of water, the adversity of strong winds, the field problems related to ground truth collection and the necessity of a better understanding of the diurnal radiation behavior of soils and rock surfaces.

4.5 Field Infrared Radiation Measurements

In order to better understand the diurnal thermal radiation behavior of typical soils of the study area, two separate experiments were conducted on a daily basis in order to obtain radiometer readings at close intervals. After examination of the previous statistical approach, it was obvious that things were happening in time that could not be reflected by statistical correlation or by smoothening of curves and averaging of values. Although the statistical methods helped establish certain conclusions, variations in terms of time of day (hours) were obviously left out. These two experiments were conducted to procure (1) a better understanding of soils diurnal thermal phenomena (2) an evaluation of factors influencing thermal radiation and (3) additional information on the optimum time for taking far infrared imagery.

4.51 Field Measurements of August 12-13, 1967

The first experiment was designed to take radiometer readings, with the Barnes PRT-4 instrument, every hour, on eight different targets, over a period of 24 hours or longer if possible. Problems were encountered during this experiment: problem of poor portability of the instrument (the PRT-4 weighs 28.5 pounds, the DC-AC inverter about 8 pounds, and a 12-volt battery about 20-25 pounds) combined with the problem of taking notes as well as problems of traffic on Highway-37 at peak hours. Two persons were required to conduct the experiment and a car was utilized to travel between the test sites.

The results of this 24 hour experiment are illustrated on Figure 56. From these curves the following remarks can be stated:

IRRADIANCE and TEMPERATURE (8-14 μ) vs TIME OF DAY for DIFFERENT MATERIALS

Instrument: Barnes PRT-4 Radiometer

Date taken August 12-13, 1967

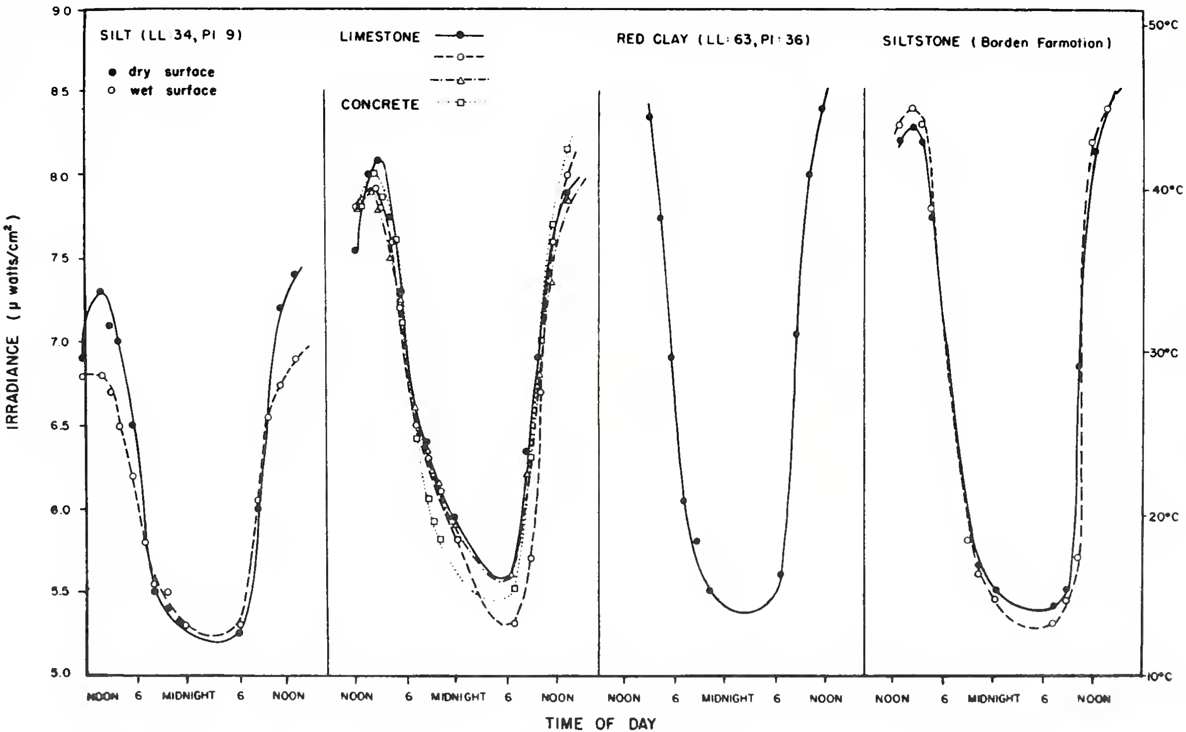


FIGURE 56 THE AUGUST 1967 INFRARED RADIATION MEASUREMENTS

(1) All materials showed, as expected, a similar set of sinusoidal daily temperature change, but the maximum temperature levels differed substantially.

(2) The morning temperatures for all the materials were about the same, within a range of four degrees Celtius. The maximum temperatures varied over 12 degrees and more; since the maximum temperature for red clay was not attained, the total range could not be ascertained.

(3) The temperature for the moist silt, at stations 25 and 26, was found to be five degrees cooler than the dry silt at the same stations. Also, the rate of cooling for the dry silt was greater than for the moist silt: this can be observed by the lag or delay of the cooling curve for moist silt and its slope. Temperature inversion points for these two conditions were found at 5:30 P.M. and 9:30 a.m.

(4) Concrete and three different limestone outcrops had somewhat similar behavior and peak temperatures and they could not, for all practical purpose, be differentiated on the basis of their peak temperature.

(5) The red clay was much warmer than the other materials and the instrument dial read off scale.

(6) The siltstone was a little warmer than the limestones and concrete but cooler than the red clay at peak temperature.

(7) There is an indication that the darker the color of the substances, the warmer they can get; but this applies only to relatively dry materials. Moisture is shown to be a major

factor that may possibly change the order of things. Further study is needed at this stage for supporting this point.

(8) The temperature inversion times are considered to be important: they are listed below for the respective materials investigated. The inversion temperature in degrees Celtius is given in parenthesis.

a	-	dry silt-wet silt	:	7:30 pm and 9:30 am (17.5) (24)
b	-	dry silt-limestones	:	6:00 am and 9:30 am (13.5) (26)
c	-	dry silt-red clay	:	N.A. N.A.
d	-	dry silt-siltstone	:	6:30 am and 10:00 am (14.5) (29)
e	-	wet silt-limestones	:	7:30 am and 9:30 am (13.5) (28)
f	-	wet silt-red clay	:	N.A. N.A.
g	-	wet silt-siltstone	:	6:00 am and 10:00 am (13) (26.5)
h	-	limestones-red clay	:	[3:30-5:00 pm] [3:30-6:30 am] (38.5-33) (14.5-18)
i	-	limestones-siltstone	:	[5:00-8:30 pm] [3:30-10:00 am] (37-26) (15-36)
j	-	red clay-siltstone	:	4:30 pm and 4:00 am (37) (14.5)

These data show the temperature inversion times, as obtained by superposition of radiometer apparent temperature curves, indicate not only a spread of hours of the day but also a spread of inversion temperature values as well. If the point

of temperature inversion is evoked to indicate a best time for taking infrared imagery, the results here indicate that this is valid for dry and wet materials of a similar nature but it is not clear that it can be extended to materials of a different nature.

(9) It appears that the time at which peak temperatures occur is believed to be the optimum time for taking imagery for the purpose of distinguishing materials on the basis of their maximum temperature, but this not true for all materials. The peak temperature time range for the materials investigated was from 1:00 to 3:00 pm. These data indicate that more has to be known on soils heat capacity under different field conditions.

(10) The after-sunset and pre-dawn period (for August 12-13, 1967, this was from 10:00 pm to 6:00 am) seems to be of major interest in terms of "quiet" infrared behavior of materials: the cooling is at a minimum and the direct solar energy complicating effects are absent. Figure 56 shows that limestone and concrete are warmer and thus they could be detected before dawn.

4.5.2 Field Measurements of September 6-7, 1968

From the above results, it was felt that other diurnal measurements should be obtained with more numerous moisture content measurements, better weather records and a longer elapsed time for the experiment. Measurements over a continuous period of two days were undertaken.

Due to the difficulties encountered in the field for the August 12-13, 1967 measurements ranging from high density traffic road, inconvenient lighting for reading the instrument at night, power supply problem to the

fact of having just one radiometer to constantly monitor several targets, it was then decided to run the experiment at one single place.

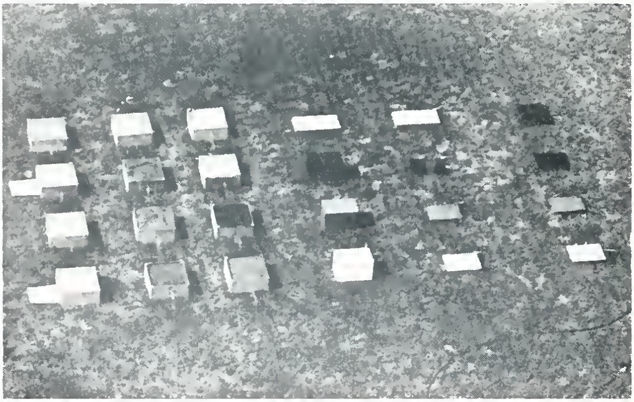
The experiment was conducted on the west side lawn near the Civil Engineering building, Purdue University, during the 48-hour period of September 6 and 7, 1968. Plywood boxes (18"x18"x8") were made to contain large samples of the representative soils of the study area and other contrasting materials as shown in Figure 57.

The prevailing weather for September 6th was sunny with clear skies, except for an estimated 30-40 percent cumulus cover at 3:30 pm which had completely disappeared by 7:30 pm. Winds were 0-5 mph from the west and were as high as 14 mph at the nearby Purdue farm at noon. Because of tall buildings surrounding the test site no major wind effect was recorded. Dew was first noticed at 2:30 am (September 7th) and reached a maximum at 7:30 am.

The prevailing weather for September 7, 1968 was sunny with clear skies. Cirrus clouds were noticed at noon time. Gusts of wind were also observed at the same time and affected the apparent temperature readings. They were estimated at the site to be between 5 and 10 mph. At the Purdue Agronomy Farm the fastest passing mile of wind was recorded to be 10 mph. The cloud cover at 3:30 was estimated at 30-40 percent and at 7:30 pm it increased to an estimated 60-70 percent but was less than about 15 percent at 9:00 pm (see Appendix 3).

Table 9 lists the materials studied and their conditions. The dry samples were oven dried for 24 hours and cooled to ambient temperature before the experiment. The wet samples were water saturated to the point where water was nearly ponded on the surface. The moist samples

(a)



(b)

FIGURE 57 FIELD INFRARED RADIATION MEASUREMENTS WITH A BARNES PRT-5 RADIOMETER, ON SEPT 6-7, 1968

TABLE 9

MATERIALS STUDIED IN THE SEPT '68 APPARENT TEMPERATURE EXPERIMENT

Box No.	Material	Conditions	Test Site No. or Origin	Thermometers
1	silt	dry	25-26	3
2	silt	moist	25-26	3
3	silt	wet	25-26	3
4	silt	dry	15	3
5	red clay	dry	19-20-21	4
6	red clay	moist	19-20-21	4
7	red clay	wet	19-20-21	3
8	silt	moist	15	3
9	muck	dry	N. of W. Lafayette	3
10	muck	wet	N. of W. Lafayette	3
11	$\frac{1}{4}$" pea gravel	dry	Verplank Plant, W. Laf.	3
12	sand	dry	6	3
13	cardboard box	white & dry	-	1
14	cardboard box	red & dry	-	1
15	cardboard box	black & dry	-	1
16	dolostone	dry	Delphi quarry	1
17	$\frac{1}{4}$" pea gravel	white & dry	Verplank Plant, W. Laf.	1
18	$\frac{1}{4}$" pea gravel	red & dry	Verplank Plant, W. Laf.	1
19	$\frac{1}{4}$" pea gravel	black & dry	Verplank Plant, W. Laf.	1
20	dolostone	dry	Delphi quarry	1
21	1" gravel	white & dry	Verplank Plant, W. Laf.	1
22	1" gravel	red & dry	Verplank Plant, W. Laf.	1
23	1" gravel	black & dry	Verplank Plant, W. Laf.	1
24	coal	dry	-	1
25	grass	-	-	0

were at the field moisture content, as collected a few days before. The moist samples were kept covered until they were exposed at the site one day before the experiment.

Glass thermometers were used to monitor the temperature at different depths of the soil samples. The wooden boxes were drilled at 3/4", 2-1/4" and 4-1/2" on one side to insert the glass thermometers (see Figure 57-a). The overall experiment set-up is illustrated in Figure 57-b.

Moisture contents were checked periodically over the 48-hour experiment by taking small soil samples at the surface of each box by scraping gently with a spoon the one quarter inch top layer. The samples were small and did not seem to noticeably affect the sample equilibrium nor the apparent temperature. The moisture was determined by the standard 24-hour oven dry loss method. All the sample boxes that contained moist and very wet soils were laid outside for a period of one day previous to the experiment to reach equilibrium. The apparent temperature was measured with a Barnes PRT-5 thermistor bolometer radiation thermometer operating on AC current (110 volts) and recording radiation in the 8-14 micron band. The instrument is essentially based on the same principle and fabrication as for the PRT-4 but was found to be much more stable, of overall improved design and much easier to handle. It has an improved three-level temperature scale and the appropriate level is selected by a switch.

4.53 Results of the September 6-7, 1968 Apparent Temperature Experiment

Figures 58 to 60 illustrate the apparent temperature results obtained. They also indicate the glass thermometer temperatures at the one-quarter

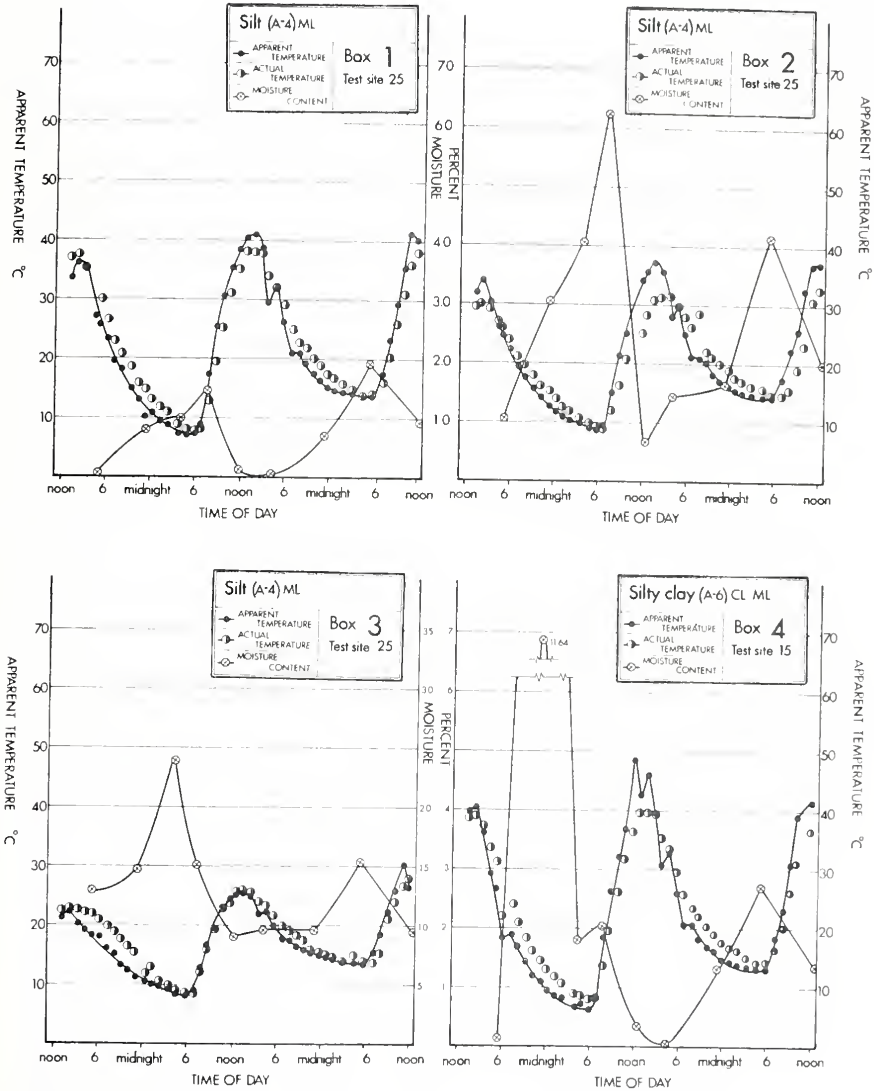


FIG. 58 APPARENT TEMPERATURE (8-14μ) vs TIME OF DAY FOR VARIOUS MATERIALS

Recorded September 6-7, 1968 with the BARNES PRT-5 Radiometer

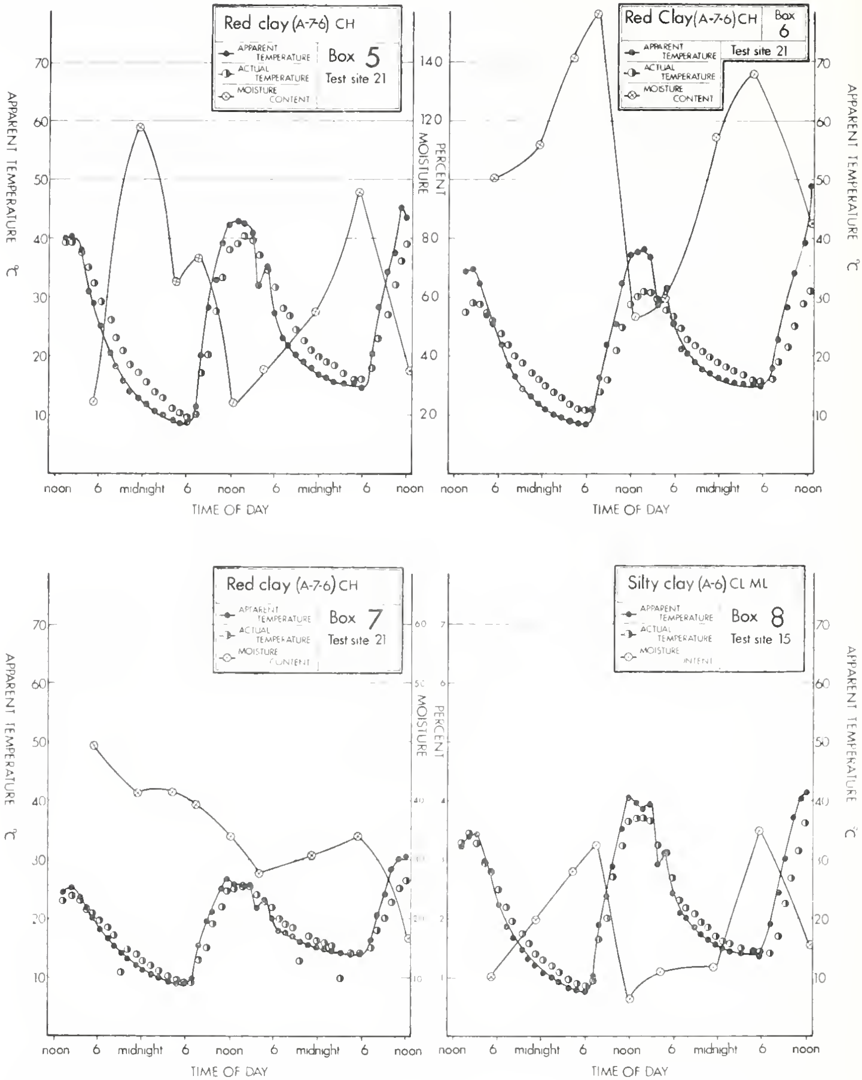


FIG. 59 APPARENT TEMPERATURE (8-14μ) vs TIME OF DAY FOR VARIOUS MATERIALS

Recorded September 6 7 1968 with the BARNES PRT 5 Radiometer

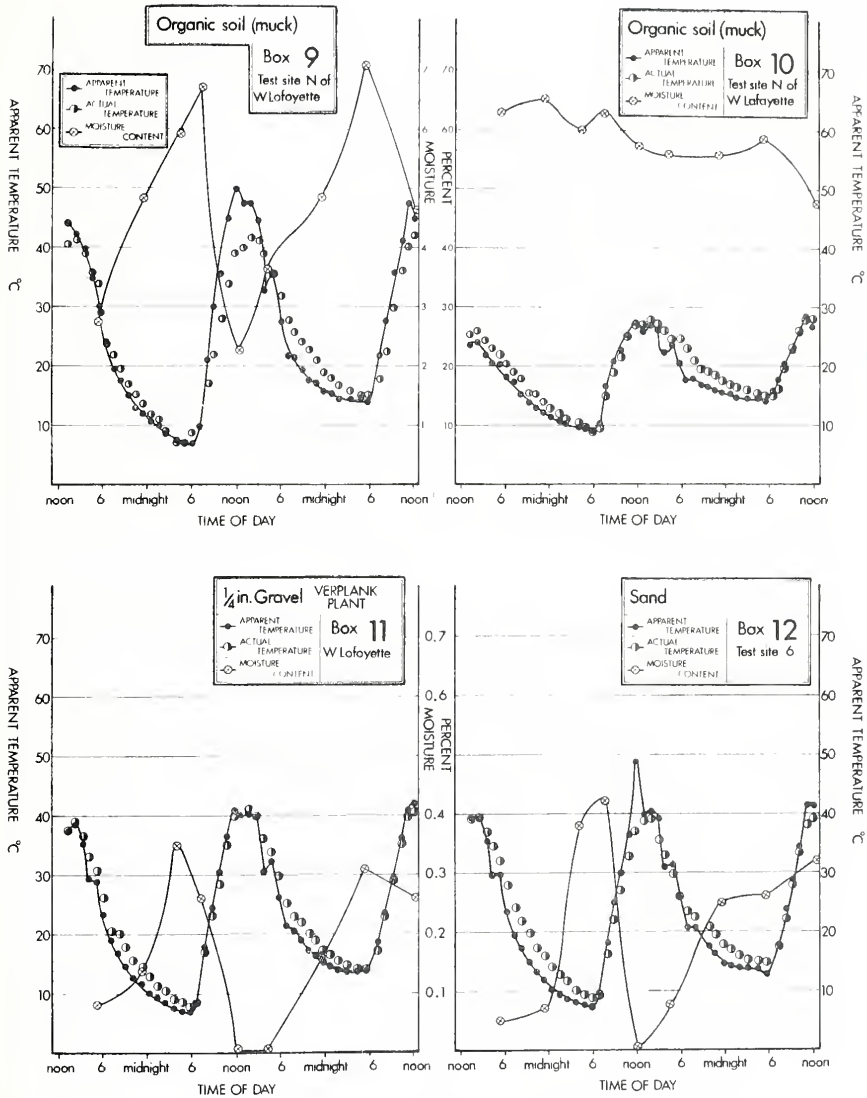


FIG. 60 APPARENT TEMPERATURE (8-14μ) vs TIME OF DAY FOR VARIOUS MATERIALS

Recorded September 6-7, 1968 with the BARNES PRT-5 Radiometer

inch depth and the moisture variation over a 48 hour period. From these results the following general conclusions are drawn:

(1) All materials again showed the typical sinusoidal curves following the daily temperature variation.

(2) The moisture variation also followed a rough sinusoidal behavior but this variation was in opposition of phase with the apparent temperature.

(3) The glass thermometer temperature slightly differed from the apparent temperature by a small amount (generally less than five degrees Celtius) and slightly lagged the apparent temperature variations: this is explained by the damping effect of the soil layer covering the glass thermometer.

(4) The great influence of moisture content over the apparent temperature was observed for all the wet samples.

(5) The PRT-5 radiation thermometer proved to be useful in determining rapid radiation changes which could not be detected by the glass thermometers.

(6) Although the experiment was not sophisticated in a way and was not fully automatically monitored as was desired, it was revealed to be of extreme value in terms of basic understanding of soil thermal behavior and in terms of more specific conclusions stated below on the variables affecting radiation. For these reasons, similar experiments should be repeated for other materials and other environmental conditions.

In order to be able to draw more specific conclusions from this experiment, Figures 61 to 65 were prepared: they compare

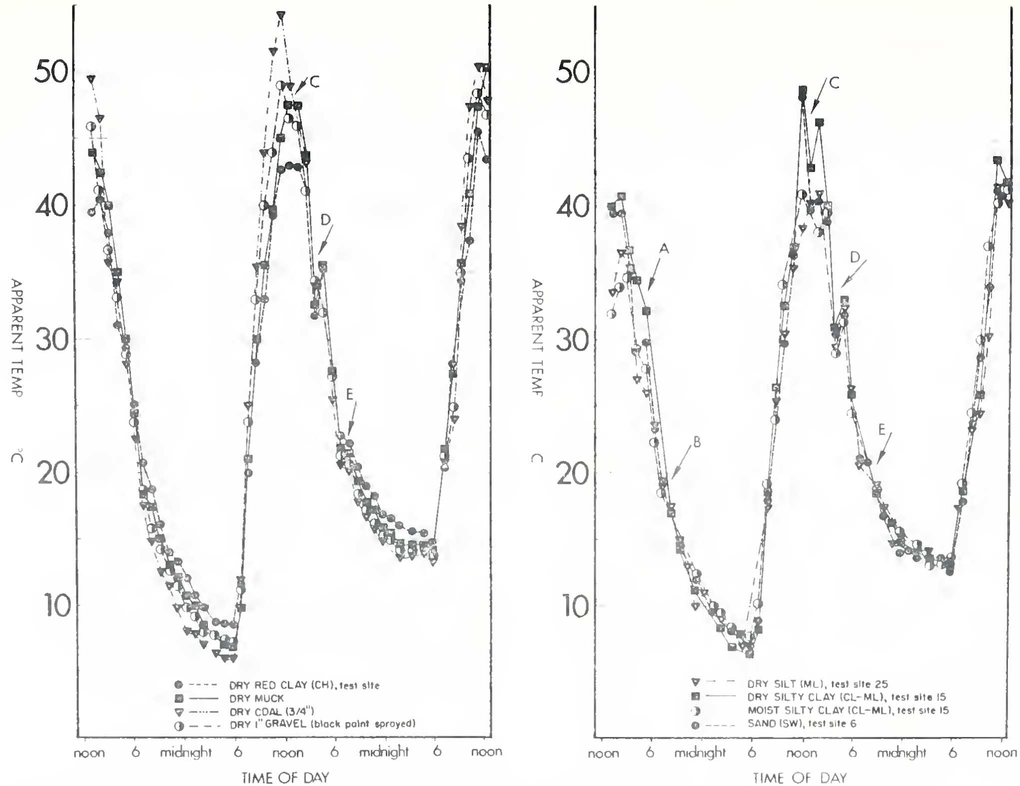


FIGURE 61 APPARENT TEMPERATURE (8-14μ) vs TIME OF DAY FOR VARIOUS MATERIALS

Recorded September 6-7, 1968 with the BARNES PRT-5 Radiometer

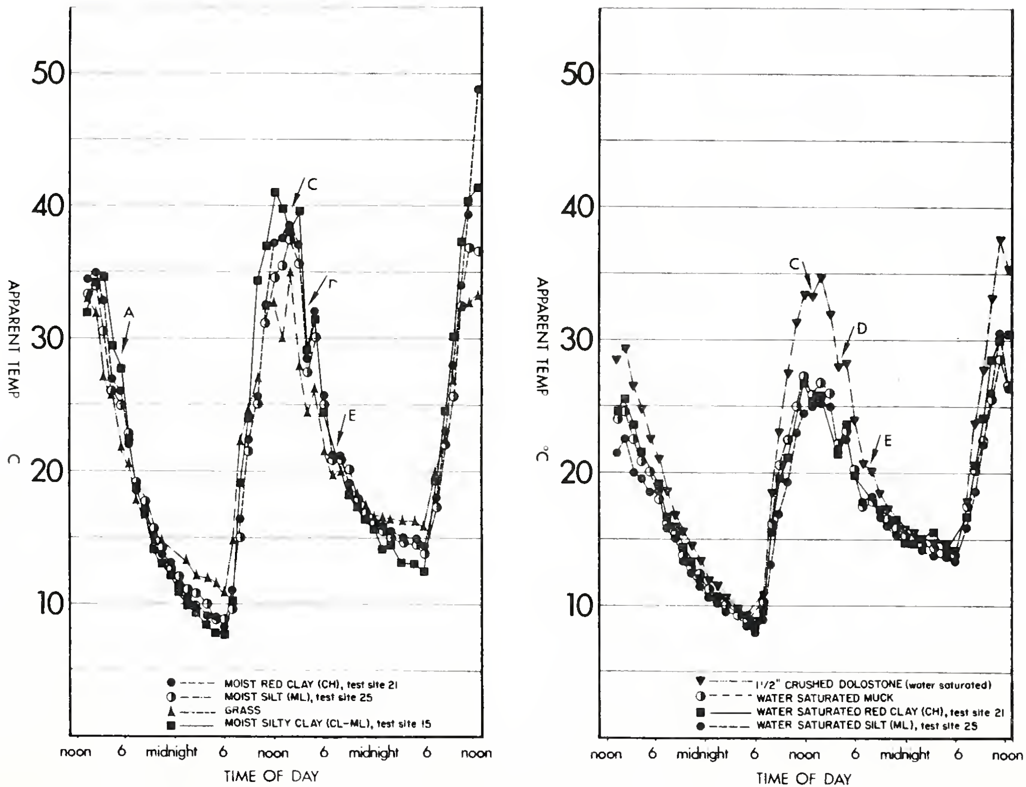


FIGURE 62 APPARENT TEMPERATURE(8-14μ) vs TIME OF DAY FOR VARIOUS MATERIALS

Recorded September 6-7, 1968 with the BARNES PRT-5 Radiometer

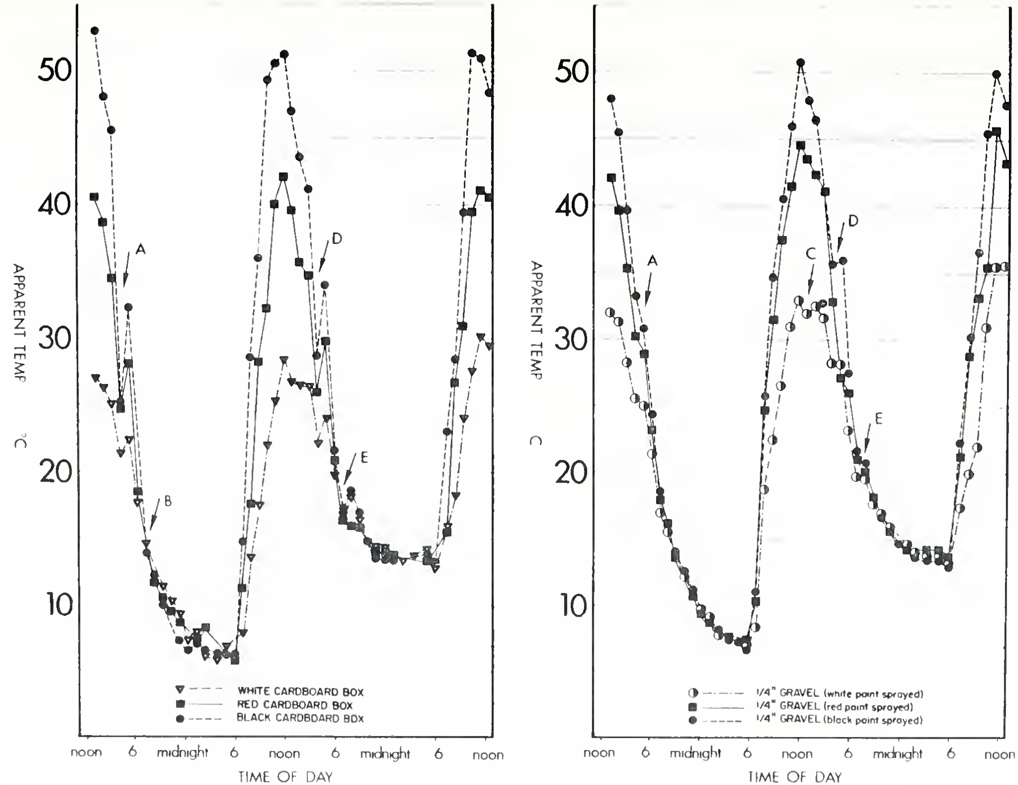


FIGURE 63 APPARENT TEMPERATURE(8-14μ) vs TIME OF DAY FOR VARIOUS MATERIALS

Recorded September 6-7 1968 with the BARNES PRT-5 Radiometer

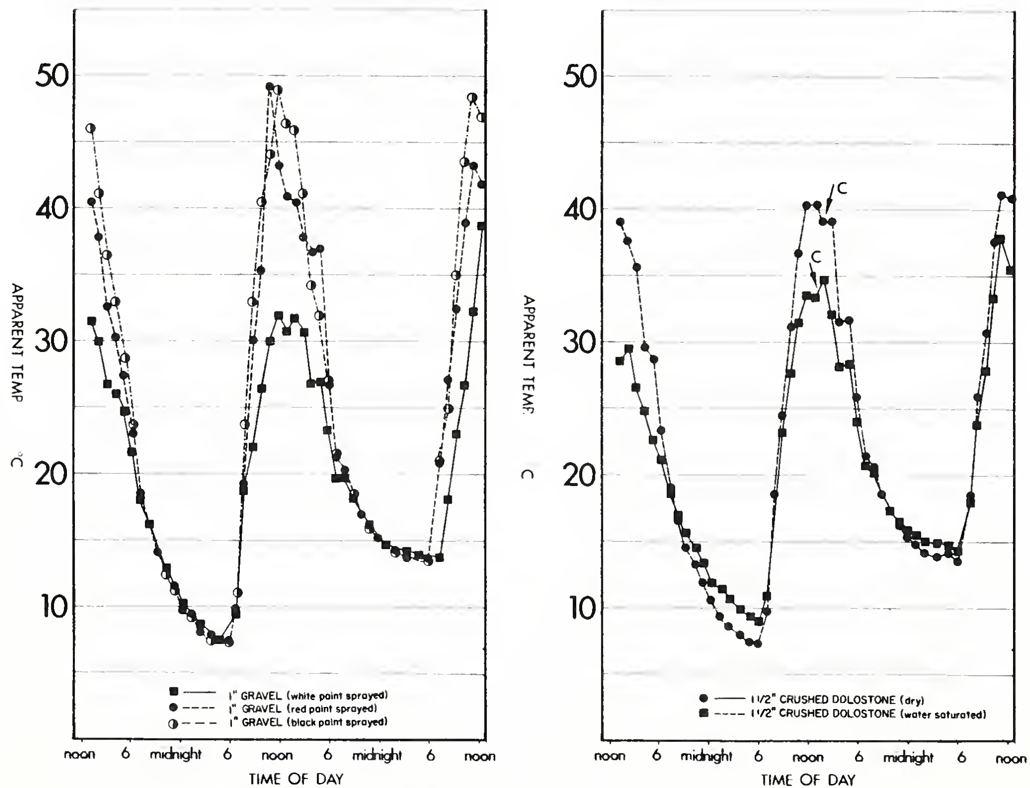


FIGURE 64 APPARENT TEMPERATURE(8-14μ) vs TIME OF DAY FOR VARIOUS MATERIALS

Recorded September 6-7, 1968 with the BARNES PRT-5 Radiometer

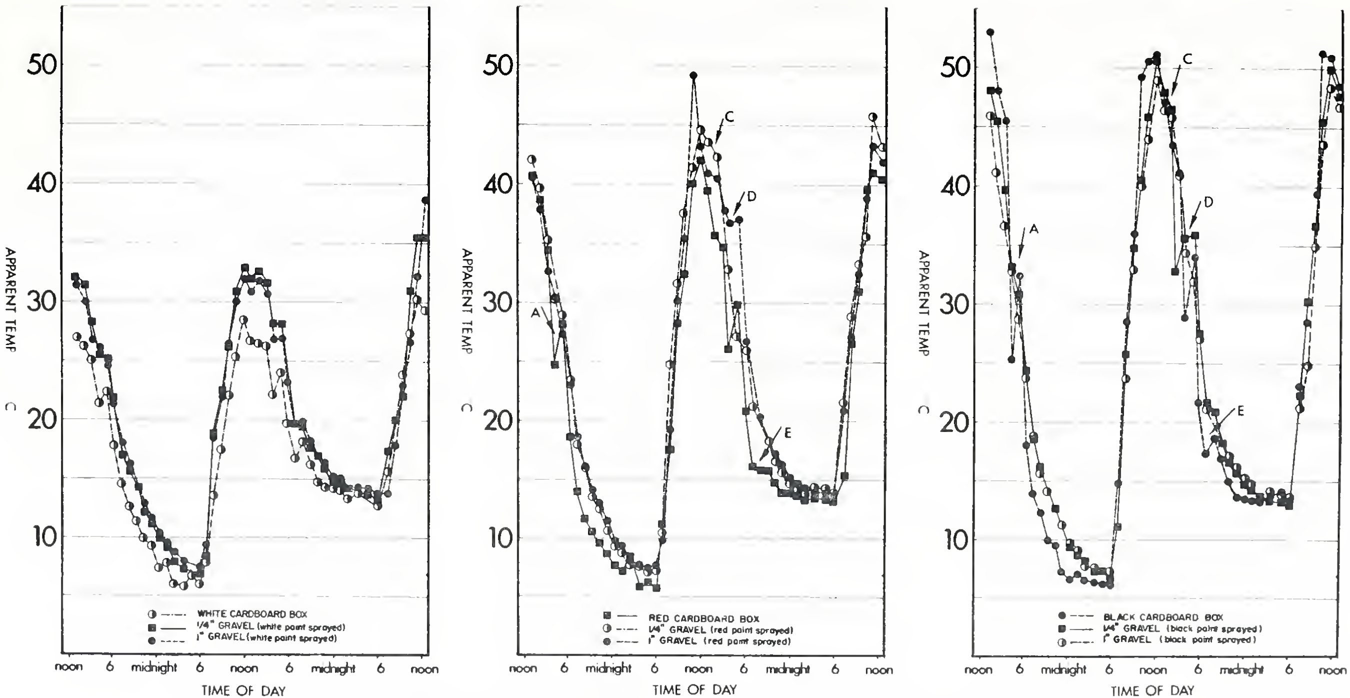


FIGURE 65 APPARENT TEMPERATURE (8-14μ) vs TIME OF DAY FOR VARIOUS MATERIALS

Recorded September 6-7, 1968 with the BARNES PRT-5 Radiometer

the apparent temperature curves for the different materials and conditions. From these figures it is concluded that:

(7) The effect of color over the apparent temperature, which to a certain extent may reflect the mineral nature of materials, appeared to be significant only at peak temperature periods, between 11:00 a.m. to 3:00 p.m. During this period, some of the dry materials were definitely warmer or cooler than some of the others: The coal sample showed to be wormer than any other; the dry silty clay of test site 15, the sand, the dry much and the black painted one-inch gravel appeared to be at the same temperature and could not be distinguished on the basis of peak temperature. The dry silt from test site 25 showed to be the coolest of all the dry samples.

In terms of color of the materials, the peak temperatures did not permit us to differentiate all the materials: this was shown by the colored cardboard boxes and the colored gravels (see Figures 63 and 64). It is concluded that only certain dry materials can be identified by their peak daily temperatures.

(8) The effect of moisture was found to be very significant. Moisture proved to have a damping affect on the apparent temperature contrast for the different materials. For the wet samples, the damping was still greater except for the dolostone. This is explained by the fact that the surface of the 1-in. crushed dolostone was dry and the coarse fragments sticking out of the water were dry and thus slightly warmer. It is concluded that moist and wet materials cannot be distinguished on the basis

of their daily peak temperatures but important information can be gained on the degree of moisture. The 8-14 micron region would reveal to be most useful, at peak temperature time, to obtain information on moisture conditions of soils (accepting that sufficient ground truth is available) but not on their nature.

(9) The effect of surface texture and grain size effects were studied. Figure 65 indicates that the apparent temperature is relatively little affected by the surface texture and/or the grain size of materials. It indicates that color is much more important.

(10) The effects of weather on the apparent temperatures were observed during this 48-hour experiment. On Figures 61, 62, 63, and 64, the weather effects that could be noticed are indicated by capital letters and arrows. Point (A) corresponds to the formation of a cumulus cover (30-40% estimated coverage) which came in at a low altitude (approx. 2000-2500 feet). Its effect was to slow down the sample cooling as clouds act as good thermal radiators. Point (B) corresponds to the time the wind was relatively calm. The 0-5 mph wind had entirely stopped at 7:30 p.m. and this reduced the rate of cooling. Point (C) corresponds to the gusts of wind at around noon to 1:00 p.m. that blew over the test area. Point (D) corresponds to the formation of cumulus clouds similar to the ones of the previous day. Point (E) corresponds to an increase in cloud cover up to about 70 percent with the absence of wind.

This monitoring of the weather conditions by visual estimation and correlation with official weather data proved most useful in determining minute radiation changes that could not be adequately explained otherwise. It shows the importance of continuously monitoring both the radiation or apparent temperature and any significant weather change that occurs. Otherwise the ground truth in terms of infrared radiation and thermal behavior of soils loses all its significance. If only apparent temperatures are to be taken at random during the day and/or without weather record backing, they would appear to be meaningless.

(11) Color, moisture, cloud cover and wind appear to be the most important factors controlling the apparent temperature and the thermal behavior of soils and other engineering materials. Of these, moisture is the most important.

(12) Thermal radiation in the 8-14 micron band is a surface phenomena highly dependent on moisture and color of the materials which may or may not have a direct relationship with its mineral nature and is independent so to speak of surface texture and grain size effects as they were studied here.

(13) It is concluded from this experiment that the 8-14 micron region is very useful to detect soils with high moisture content and very humid zones but it does not seem sufficient in itself to assist in determining the nature of materials.

(14) The optimum time for taking imagery in the 8-14 micron region is a very difficult question to answer. First, it seems to be

very dependent upon the type of information required. From the previous ground experiment it appears that temperature "contrasts" are greater at peak temperature time, between 11:00 a.m. and 3:00 p.m. for the September experiment. One would still have to know the overall air or atmosphere thermal radiation in order to theorize on the best time of flying. The idea of flying after the temperature inversion time is valid for dry versus moist materials but it is not in terms of maximum radiation. Added to this is the problem of adequate filtering of the incoming sun radiation during daytime. It is felt that more has to be done to study this problem and that there is room for both theoretical analysis of this problem and study of many more case histories of actual infrared imagery taken at daytime and at nighttime.

4.6 Multispectral Imagery Interpretation

The purpose of this section is to discuss and present the results of three different approaches taken to interpret the multispectral imagery obtained on April 28, 1967. The three approaches are (1) interpretation by close visual examination using the conventional airphoto interpretation method with the additional concept of spectral signatures of materials, (2) densitometric measurements in order to establish signatures of materials if possible and (3) the automatic method of multispectral data classification developed at the Purdue University Laboratory for Agricultural Remote Sensing (LARS).

4.61 Interpretation by Visual Inspection

During the visual examination of the imagery, all the following techniques were tried: (1) examination of the original 70 mm. negative film strips on a light table with and without magnification, and (2) examination and interpretation attempts of contact prints and enlarged (2 diameter) prints made from the negatives.

The maximum number of bands that could be handled and examined simultaneously in a convenient manner was six bands and ideally four bands. Attempts were made to visually examine the 12 bands simultaneously but the information obtained on the first few bands was forgotten by the time the 10th, 11th or the 12th band were being examined.

This first examination enabled the sorting of bands that were very closely related and thought to be essentially similar. In this manner, the following six bands were thought to be most convenient for further simultaneous examination:

the thermal infrared band	8-14 microns
the reflective infrared band	0.8-1.0 micron
the red band	0.62-0.66 micron
the green band	0.52-0.55 micron
the blue band	0.40-0.44 micron
the ultraviolet band	0.32-0.38 micron

Before any analysis and discussion of what was detected and identified or just detected and not identified on the different bands or combination of bands, it is of utmost importance to say that what follows applies only to the case history under study (the 70-mile strip along Indiana State Road 37) and to the imagery as collected on April 28, 1967

between the hours of 10:55 a.m. to 12:35 a.m. under the prevailing weather conditions as reported in Appendix 3.

In order to substantiate the conclusions of this section, five typical examples of imagery are reproduced in Figures 66 to 70. These are reproductions of the high altitude imagery (3200 feet) at a resultant scale of 1:28,800 (1 in. = 2400 ft). The low altitude imagery (1600 ft) at a resultant scale of 1:14,400 (1 in. = 1200 ft) was also examined but is not illustrated.

The following sections of imagery were selected for the given specific reasons:

Figure 66; area just south of Indianapolis, for the presence of granular materials in the White River flood plain, sand piles, ponds, a river, wet and dark soils and several man-made features.

Figure 67; area between Indianapolis and Martinsville, for the presence of two main land forms; a flood plain and a glacial moraine, several bare soil conditions and features, drainage conditions, and mottled tone of soils.

Figure 68; area southeast of Martinsville, typical because of the reworked outwash and lacustrine condition (see photo-map 2.3, Plate 9). The presence of silt mounds, drainage conditions and a highway under construction.

Figure 69; area northwest of Bloomington typical because of the residual red clay over a limestone plain.

Figure 70; area northwest of Bedford selected because of the two major terrain conditions showing a narrow flood plain with fine silts and rock control in a limestone and red clay area.

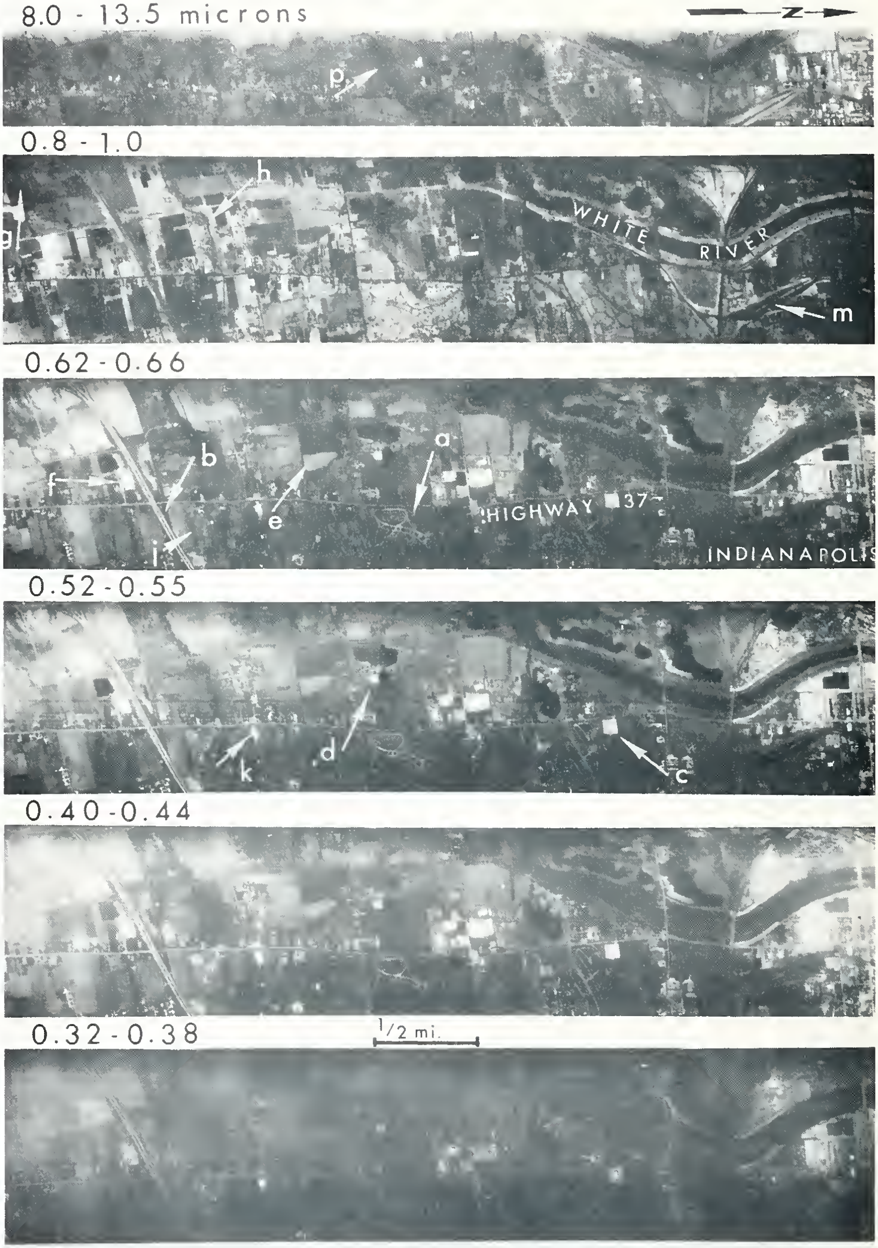


FIGURE 66 MULTISPECTRAL IMAGERY AREA I

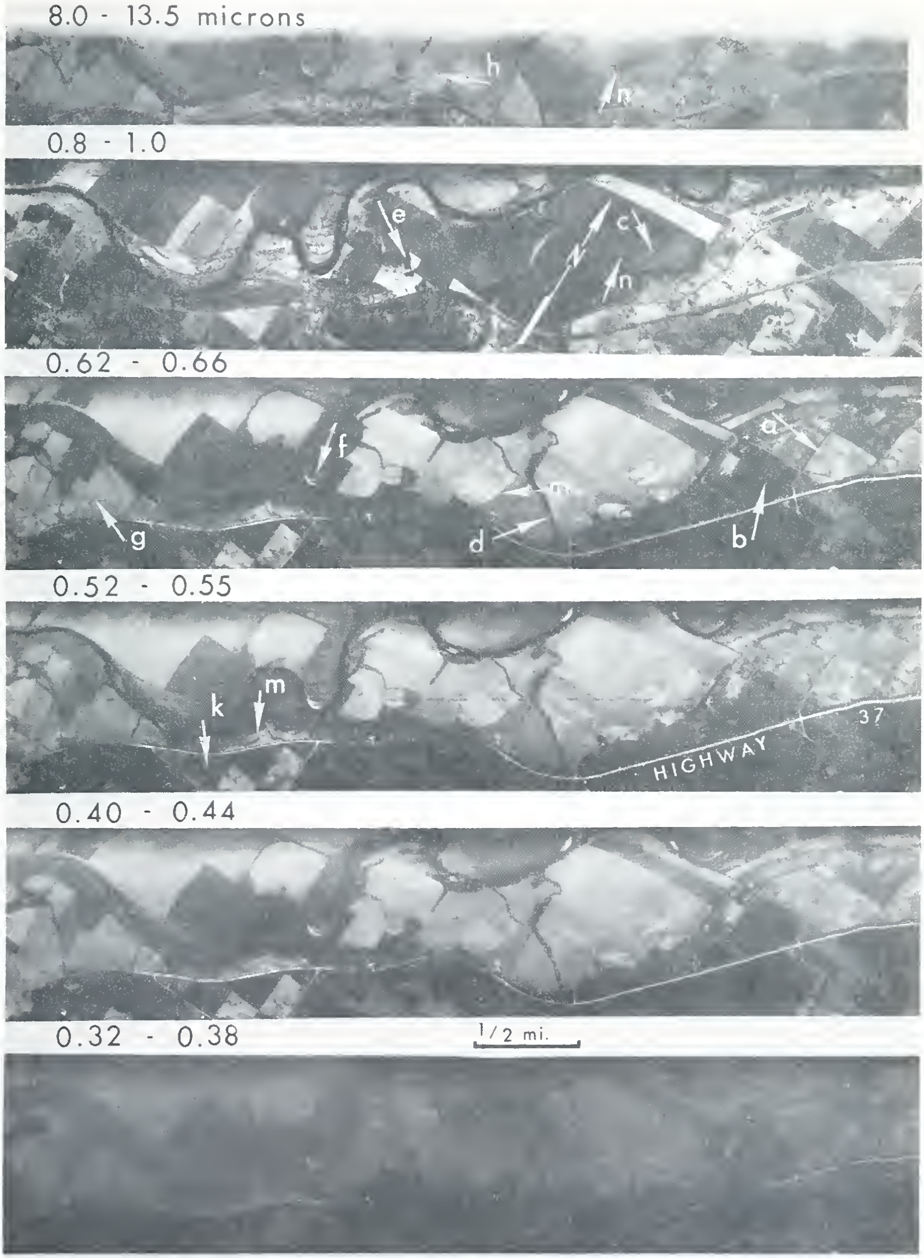


FIGURE 67 MULTISPECTRAL IMAGERY AREA 4

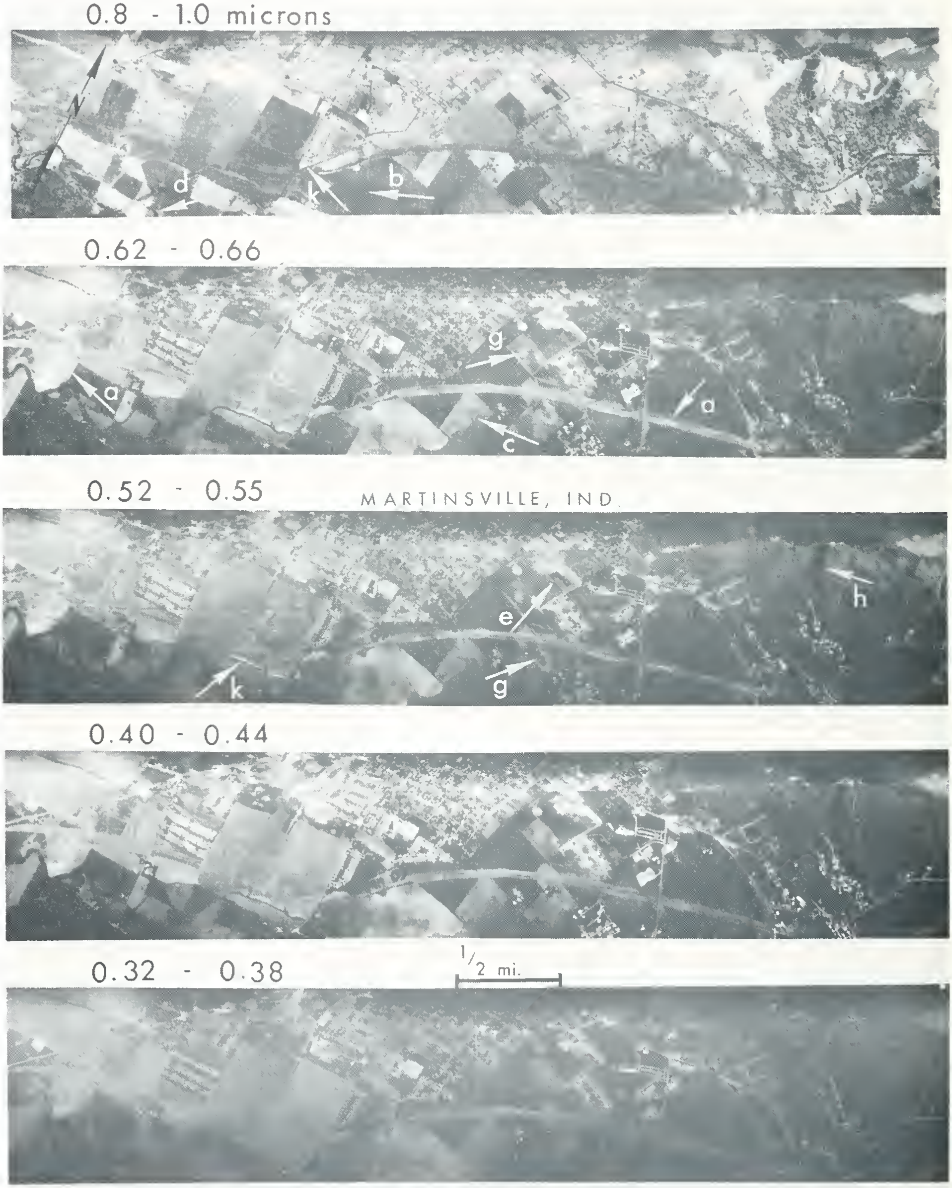


FIGURE 68 MULTISPECTRAL IMAGERY AREA 6

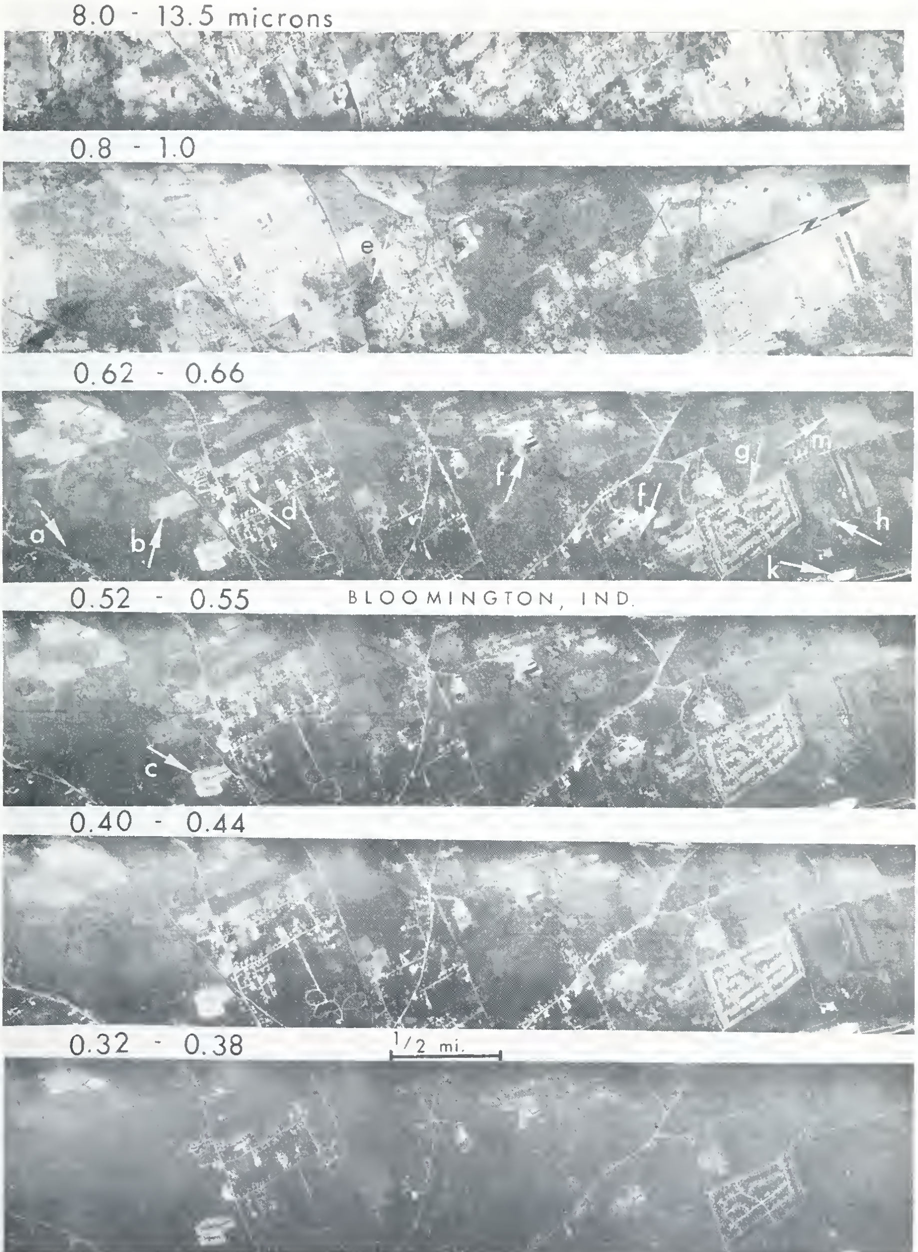


FIGURE 69 MULTISPECTRAL IMAGERY AREA 8

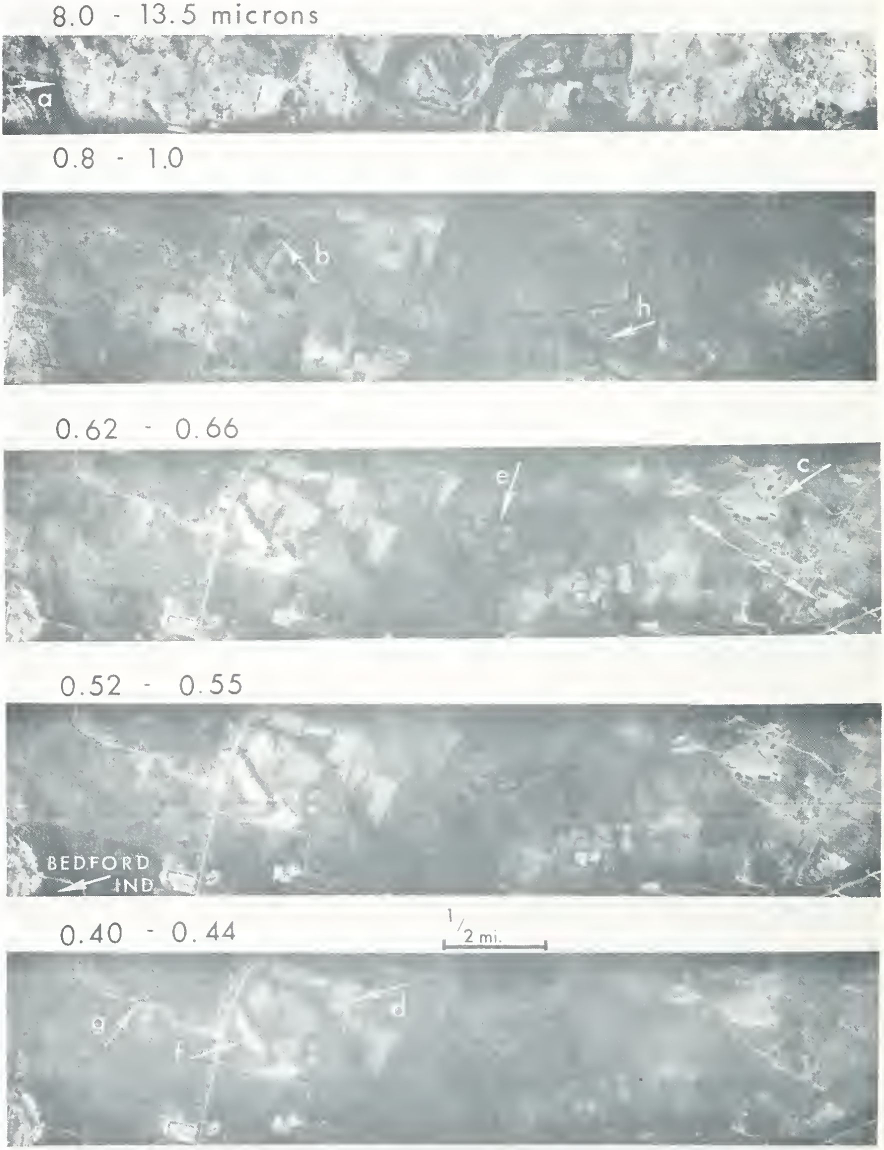


FIGURE 70 MULTISPECTRAL IMAGERY AREA 12

4.611 The Thermal Infrared 8-14 Micron Band. The thermal infrared (8-14 micron) band was particularly useful to detect bodies that were relatively hot and emitting strongly and bodies that were relatively cool. Water bodies and vegetation are considered relatively cool and showed as dark areas or items on the imagery. Certain roofs and certain roads were warmer and showed white on the imagery. Most soil areas were of the same intermediate grey tone except for a few special features. This band was useful to detect these few special features that could not be detected on other imagery bands. Two good examples are shown at item "p" on Figure 66 and item "h" on Figure 67. The first one is a slightly depressional area which corresponds to a very wet zone but it was not detected on any other band nor on any other type of film. Once it had been located on the 8-14 micron band, then it could be detected on some of the other bands and partly detected on the color infrared and color films. The feature would have been missed entirely without the 8-14 μ imagery and this is a feature of engineering importance. The second feature is a soil drainage feature that could not be detected at all on the other bands nor on the other photography, even on the color infrared.

Tonal differences in this band will change over a period of 24 hours in a very drastic way as the temperature of materials change and eventually may result in tonal inversions at night.

4.612 The Reflective Infrared Band 0.8 - 1.0 Micron. The reflective infrared (0.8 - 1.0μ) imagery was very useful to detect vegetation covered areas and bare soil areas. When examining this band, things should be visualized this way: water bodies are all very dark and uniform in tone, soils and road systems are intermediate grey tones, wet soils are darker

grey ("g" on Figure 66), and vegetation is very light grey to white. Coniferous trees ("e" on Figure 70) are medium grey to dark. Good reflectors like some galvanized steel roofs are very bright.

4.613 The Visible Red Band 0.62 - 0.66 Micron. The red (0.62-0.66μ) imagery band was found to be most useful for soil studies. Soil contrasts were shown better on this band than any other except the 0.52 - 0.55 micron band. In the red band, water bodies are dark and soils are of various shades of grey from light to medium dark. Bare dry soils are light ("d" of Figure 66, "m" of Figures 67 and 69, "b" of Figure 70). Wet soils are darker ("c" and "n" of Figure 67, "g" of Figure 66, "b" of Figure 68). Vegetation is rather dark. It is important to note that the tone inversions for soils and for vegetation occur in the 0.8 - 1.0 and 0.62 - 0.66 micron bands. These two bands in combination yield extremely significant information as discussed in the section on automatic classification.

4.614 The Visible Green Band 0.52 - 0.55 Micron. The visible green (0.52 - 0.55μ) imagery is quite similar to the previous one but soils were not as contrasty, but all the important soils features on the 0.62 - 0.66 band were also present here. For instance the mottled tones of the ground moraine of Figure 67 (item "a") still shows just as well.

4.615 The Visible Blue Band 0.40 - 0.44 Micron. This band is definitively not as interesting in terms of soil mapping. Much of the contrast between dark and wet soils and light colored soils is gone (see items "g" on Figure 66; "c", "m", "n" on Figure 67). Because of a reduction of the overall contrast and the greater reflectance of pavement materials in this range, the road systems show much better. Water bodies

are all of the same dark grey tone and cannot be distinguished from the vegetation.

4.616 The Ultraviolet Band 0.32-0.38 Micron. Only a few features show as bright tones on this band. Certain high ultraviolet reflectors are recognized such as certain roofs, concrete pavements, some older bituminous concrete pavements because of the aggregates, limestone quarries, and sand bars (see item "f" of Figure 67).

4.617 General Conclusions Based on the Visual Inspection. In order to summarize the points developed on the six bands examined, it can be stated that if there is a change in soil type due generally to color, this is evidenced in bands 0.8 - 1.0, 0.62 - 0.66, and 0.52 - 0.55 micron and in a subdued manner in the 0.40 - 0.44 band. If there is an appreciable change in the drainage of soils in the upper foot or upper few feet of soils or if a highly saturated zone is created, this is evidenced in the 8-14 micron band.

The different bands have been treated separately but they become much more significant when they are grouped, such as was stressed for the 0.8 - 1.0μ and 0.62 - 0.66μ bands. From the visual examination the following conclusions were drawn:

(1) The optimum set of imagery bands was obtained by grouping the 8-14μ, the 0.8-1.0μ, the 0.62-0.66μ and either the 0.40-0.44μ or the 0.32-0.38μ bands.

(2) Soil contrasts were best detected in bands 0.62-0.66μ and 0.52-0.55μ.

(3) Water bodies showed best in the 8-14μ and 0.8-1.0μ bands. Preferably the 0.8-1.0μ band should be used for this purpose

because of the high reflectance of vegetation in the 0.8-1.0 micron region, and the strong absorption of water in that band.

(4) The imagery suffered from lack of resolution and due to the overall small scale, even for the low altitude imagery (1:14,400).

(5) It is quite obvious that no information was obtainable from the imagery either directly or indirectly on the topography. Topography is an important element in engineering soils mapping and is entirely left out on the imagery. Soil features are often detected only locally and without continuity. This is a major problem when mapping soils. Therefore it is obvious that multispectral imagery cannot replace aerial photography. In fact it was not meant for that purpose and it should be considered as a supplement to aerial photography.

(6) There are indeed soil features and soil conditions that are either enhanced and more easily detected on the imagery than on aerial photography.

(7) There are even soil features and soil conditions that show only on the multispectral imagery which cannot even be detected on any other sensor type data.

4.618 Recommendations for Visual Analysis of Multispectral Imagery. From the experience gained through this investigation, it is recommended for future projects involving multispectral imagery that:

(1) The scale on the final imagery strip be of a scale larger than 1:12,000, ideally between 1:10,000 and 1:6,000.

(2) The film strip should be larger than 70 mm., ideally five inches

wide (problems at the processing level from analog data to imaging on the CRT can be overcome).

(3) The geometric distortion or "sigmoid" distortion necessitates the use of only the central two-thirds of the imagery for practical purposes. This is tolerable but attempts should be carried further to develop equipment for distortion-free restitution.

(4) In order to use the far infrared 8-14 micron band to the maximum of its capability, this imagery band should be obtained at night in the hours before dawn (3:00-6:00). And until more is known about the interpretation of the thermal infrared imagery, it should be flown, if at all possible both during the day and at night and considered to be two additional bands complementing each other. This would allow much better insight on infrared behavior and emissivity of materials.

(5) Simple enhancing equipment should be developed. It is critically needed for interpreting multispectral imagery by visual means.

(6) The standard photo-interpretation methods and techniques do not apply to multispectral imagery and until better approaches are devised, the imagery interpretation is and will be badly hampered.

(7) The multispectral imagery as the name indicates was developed in order to obtain the spectral characteristics of materials: it should be used with this concept in mind and since human visual means are limited in terms of number of bands that can

be simultaneously treated, efforts to further investigate multispectral imagery by visual means alone are presently discouraged at least until item (5) above is given further thoughts.

4.62 Interpretation by Densitometric Measurements

In an attempt to study the validity of the spectral signature concept [98, 99], a series of density measurements of the multispectral imagery were taken. The approach was to first measure the transmission density on a calibrated Macbeth transmission densitometer Model TD-102 with a 1 mm. aperture, for spots of interest on the imagery.

The density readings were normalized against a standard gray scale: in this manner each of the imagery sections in each band and their respective calibration grey scale levels were made comparable. For each spot of interest or target, this was done for all the imagery bands in order to compare the relative response for each target in each band and the overall spectral signature for the target materials.

Figures 71 to 74 illustrate the density results for one sample area (area 1-A). All the prime density levels that appear on these figures were normalized against the same grey scale. The letters refer to the targets indicated on the imagery. Some problems appeared due to the narrow width of the 4.5-5.5μ and 8.0-14.0μ imagery which is due to a narrower scan angle (only 37° against 80° for the other channels). (This narrower scan angle is due to the two calibration plates placed inside the scanner for calibration purposes.)

Figures 75 and 76 were prepared to illustrate the multispectral signature concept. Fields "d" and "g" were dark, wet silty soil area as

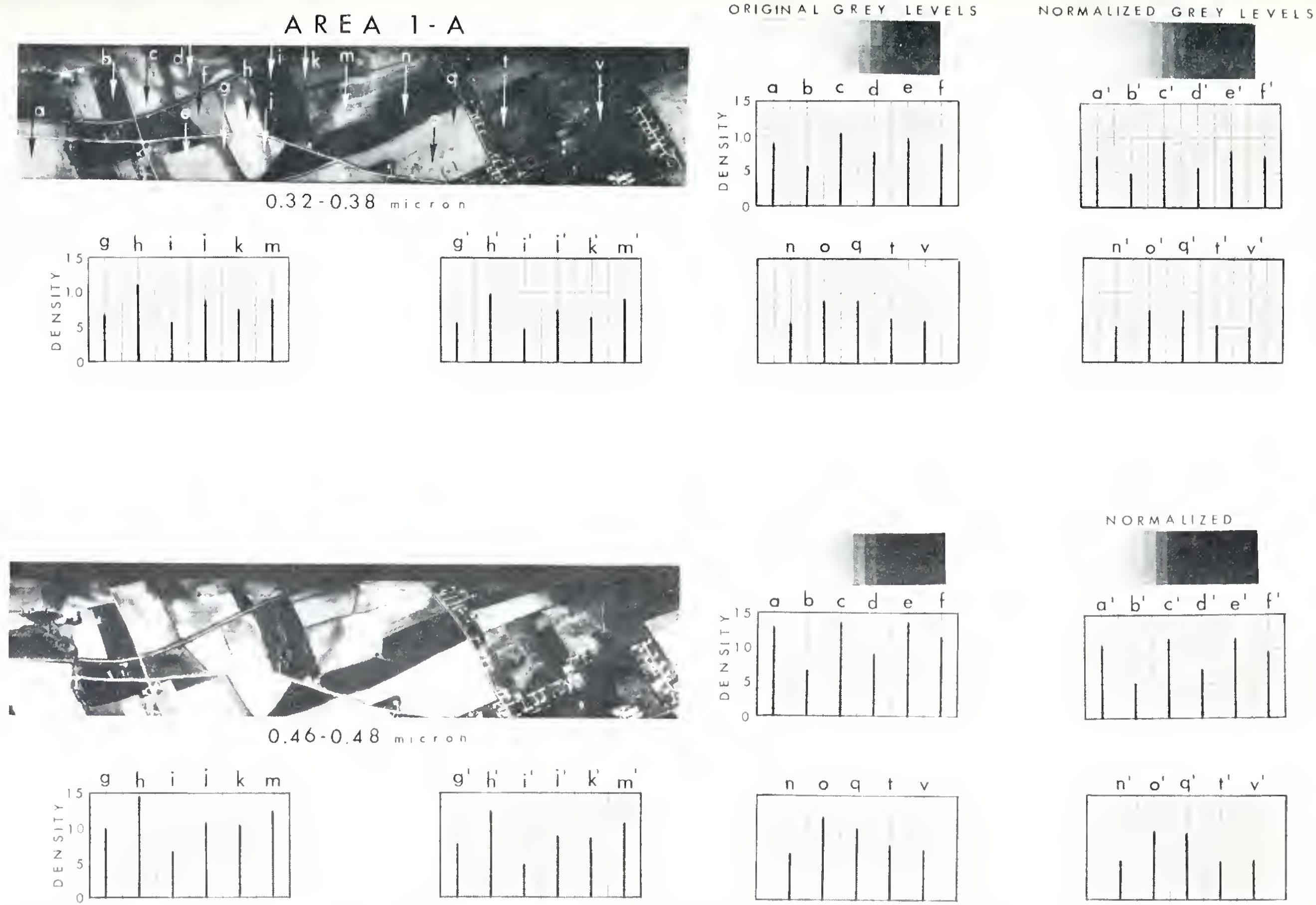


FIGURE 71. DENSITOMETRIC MEASUREMENTS ON BANDS 0.32-0.38 AND 0.46-0.48 OF AREA I-A

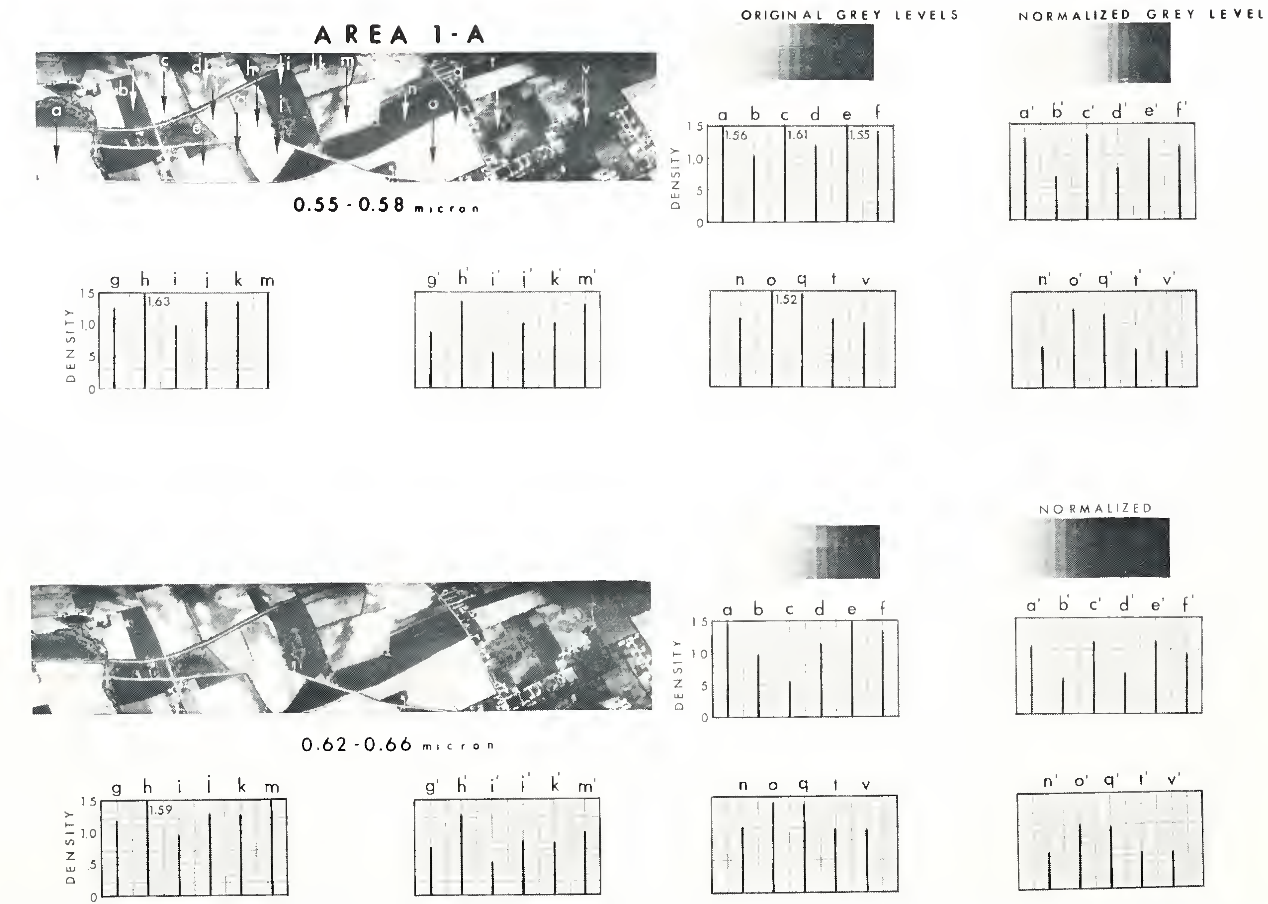


FIGURE 72. DENSITOMETRIC MEASUREMENTS ON BANDS 0.55-0.58 AND 0.62-0.66 OF AREA 1-A

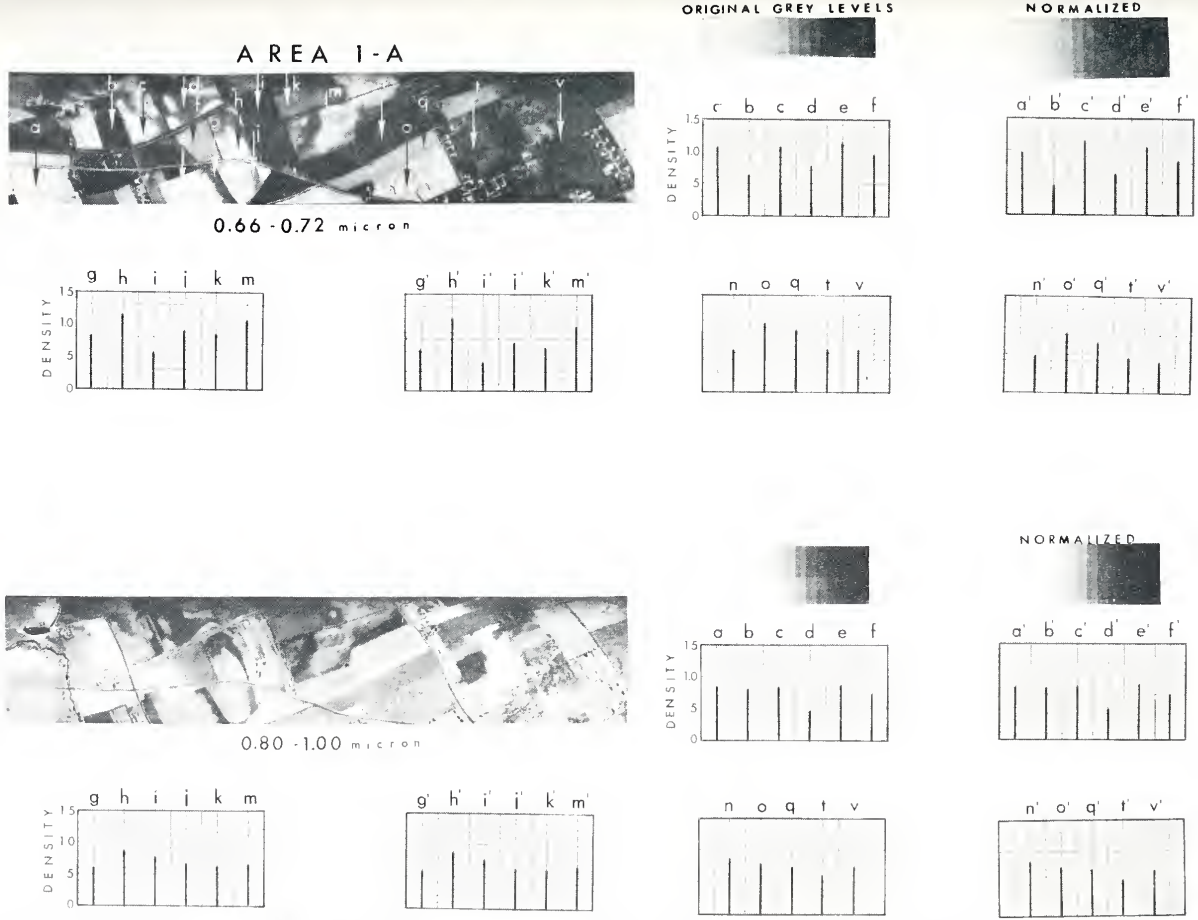


FIGURE 73. DENSITOMETRIC MEASUREMENTS ON BANDS 0.66 - 0.72 AND 0.80 - 1.00 OF AREA I-A

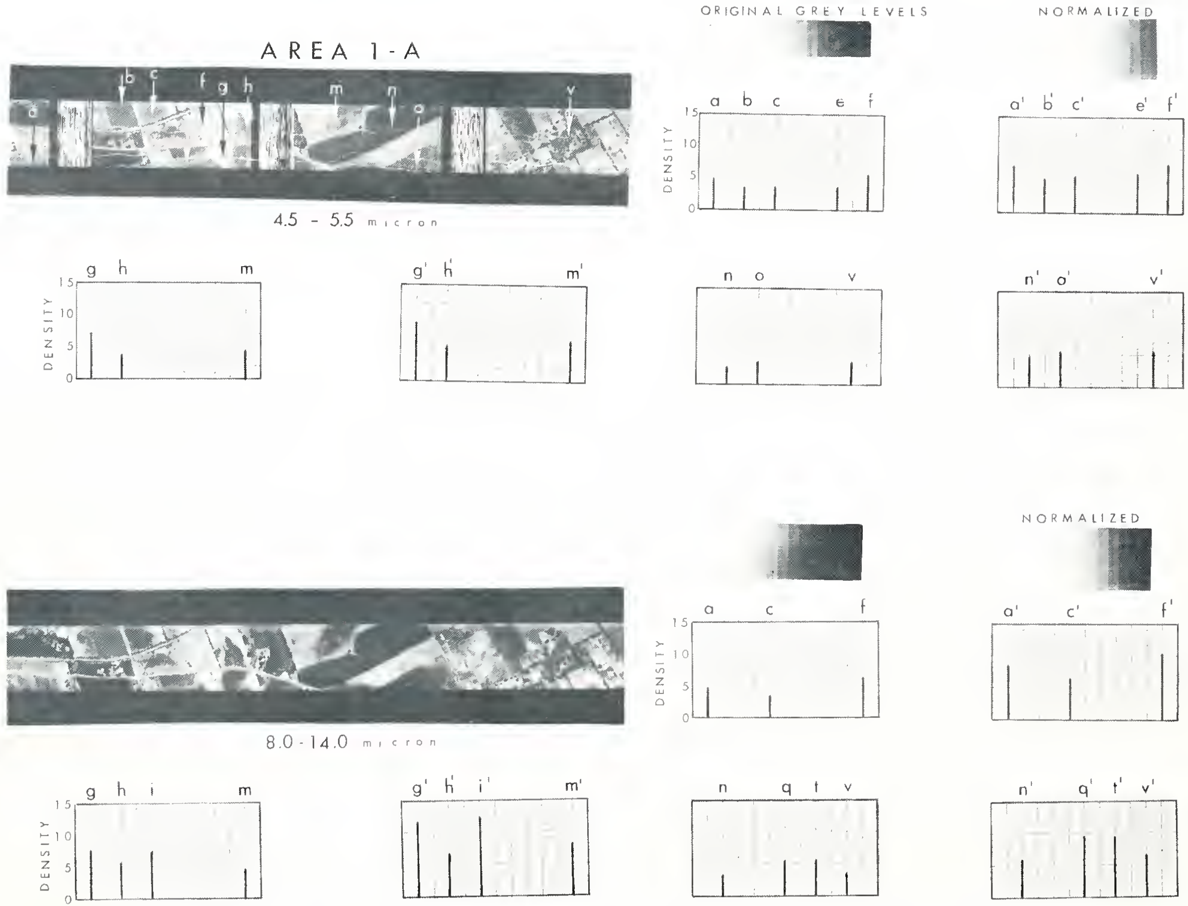


FIGURE 74. DENSITOMETRIC MEASUREMENTS ON BANDS 4.5–5.5 AND 8.0–14.0 OF AREA I-A.

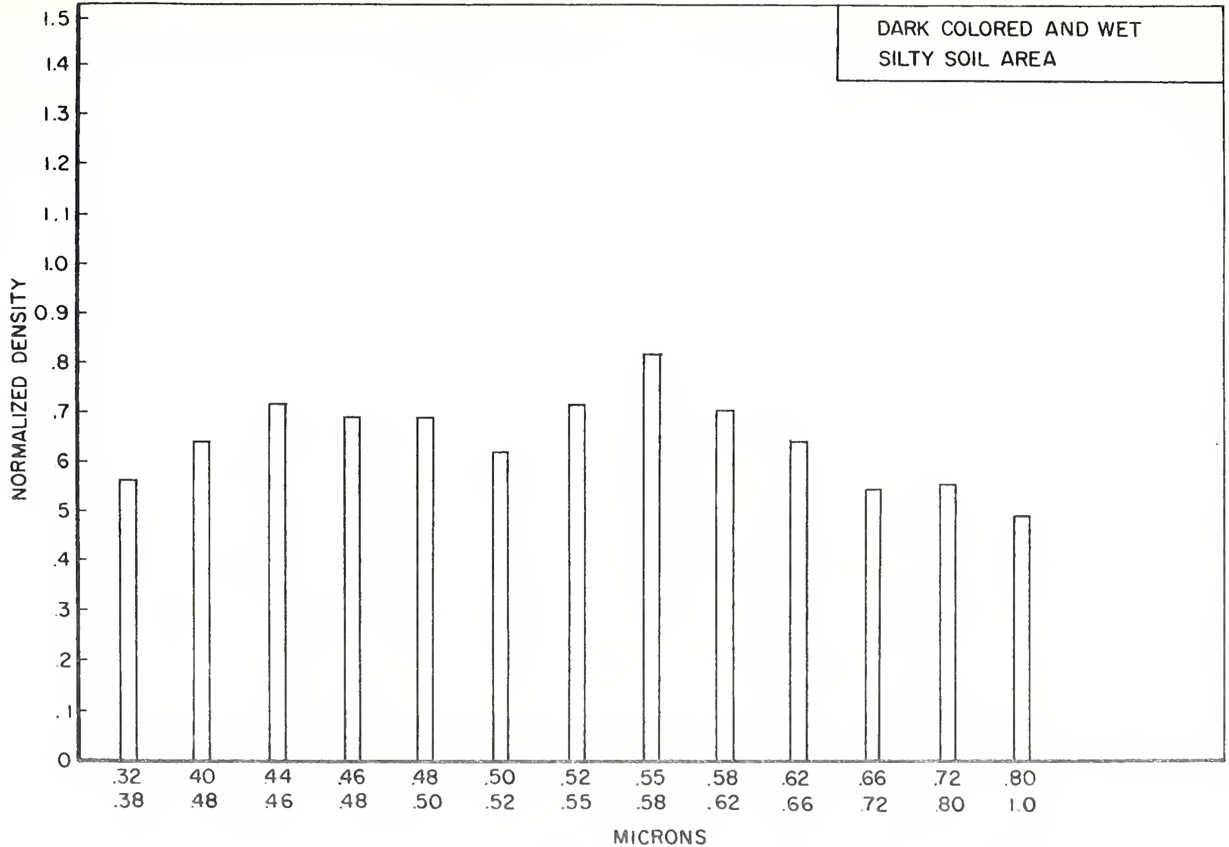


FIGURE 75. SPECTRAL RESPONSE OF FIELD "d" FROM DENSITY MEASUREMENTS.

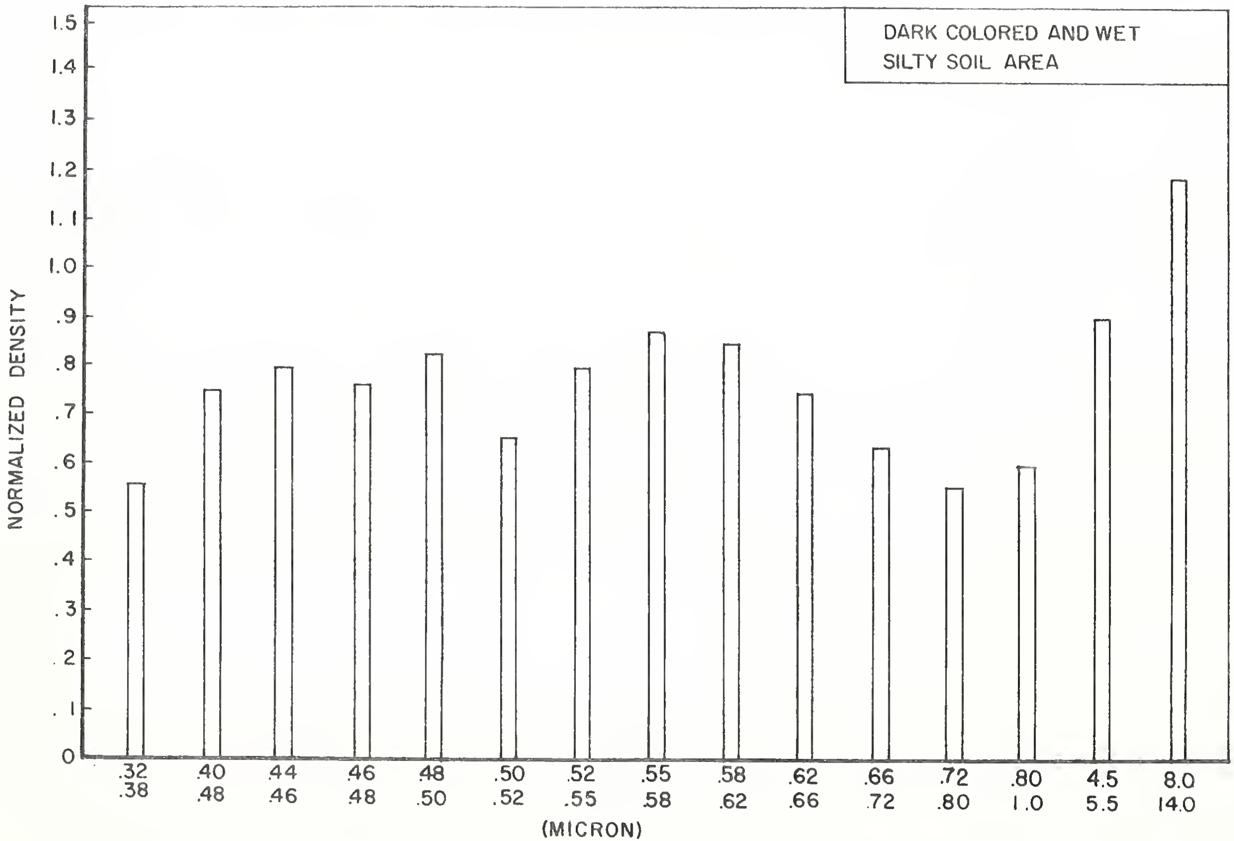


FIGURE 76. SPECTRAL RESPONSE OF FIELD "g" FROM DENSITY MEASUREMENTS.

revealed by ground truth. The multispectral response on Figures 75 and 76 are closely matched when superposed both in terms of relative intensity in between the bands (profiling or shape of the curve) and in relative intensity within one band to the nearest 0.15 unit of normalized density.

Figures 77 and 78 show the multispectral signatures for two contrasting terrain types. Fields "h" and "t" were respectively an area of dry, pale yellow-brown silt and an area of wet muck. These extremes were selected to emphasize the contrast in spectral signature. For this purpose, compare in Figure 77 the very high response in most bands except the middle and far infrared with the overall flat and low returns except for the far infrared in Figure 78. To appreciate the subtleties of the spectral signatures, the relative responses in Figures 76, 77 and 78 can be compared. They show that three significantly different materials with significantly different engineering characteristics in terms of texture and moisture content have significantly different spectral signatures also.

These results and other measurements made during the research confirmed that the concept of multispectral signature of first surfaces is a valid premise in remote sensing, that the signatures can be measured on the imagery and that they are significant in terms of engineering soils.

This phase of the research also showed the complications of the densitometric approach. It is slow and cumbersome. Long strips of imagery have to be searched and it is a tedious job to measure the densities point by point and then to normalize and plot the results. If the imagery can be readily handled by computer there is really little point in using this approach and its use is discouraged except for very special

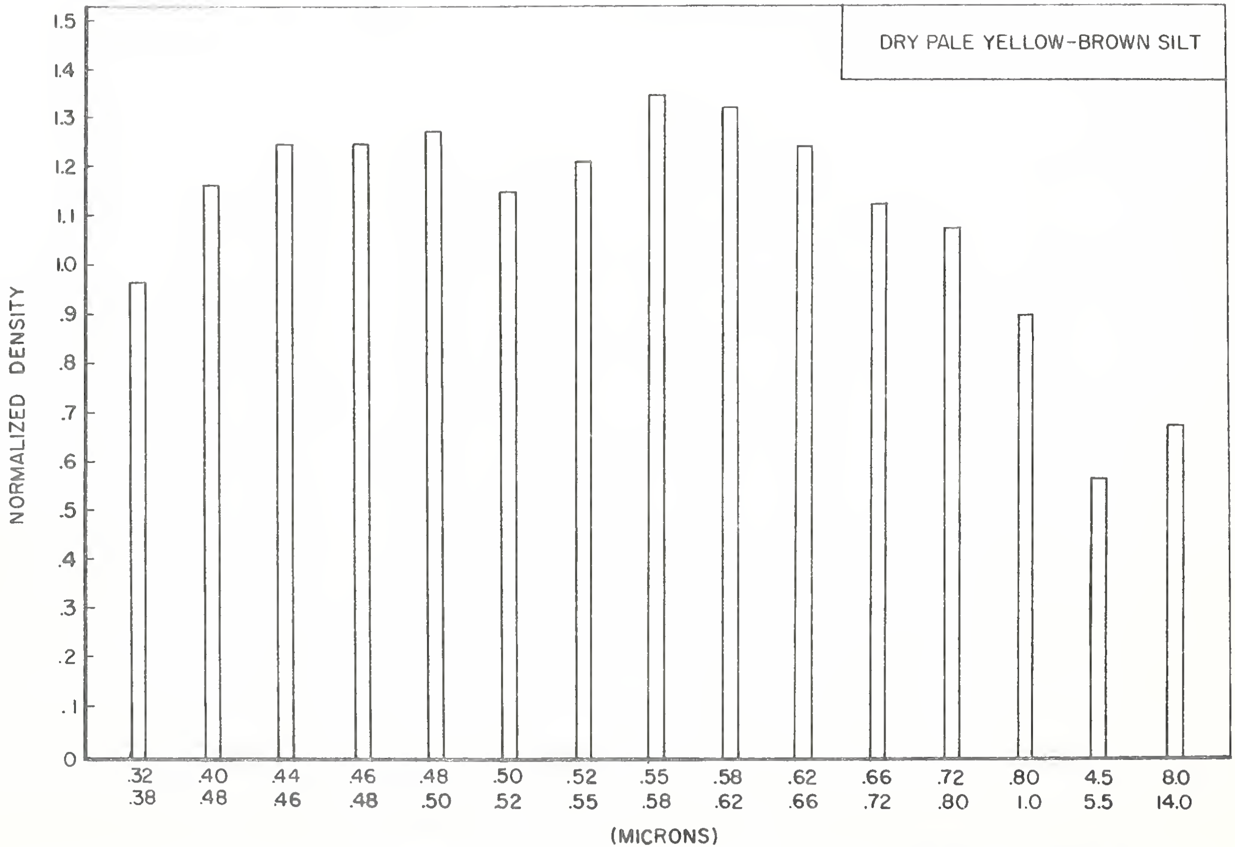


FIGURE 77. SPECTRAL RESPONSE OF FIELD "h" FROM DENSITY MEASUREMENTS.

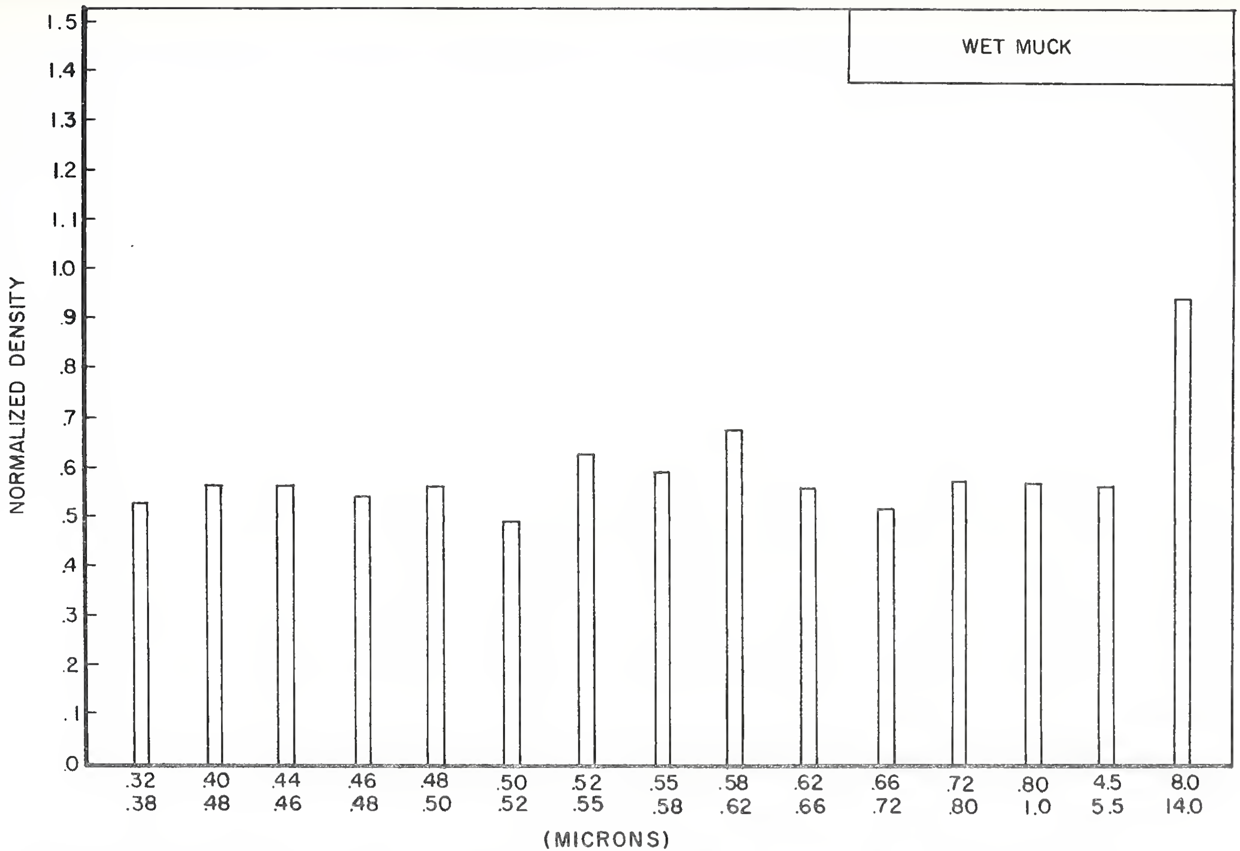


FIGURE 78. SPECTRAL RESPONSE OF FIELD "t" FROM DENSITY MEASUREMENTS.

reasons. Better methods are available as will be seen in the next section.

4.63 Thermal Measurements on the 8-14 Micron Imagery

The thermal infrared imagery film strips contain two calibration traces of two reference plates, one hot and one cold, for the purpose of thermal measurements on the imagery. Built into the scanner are the two plates at different temperatures with embedded thermistors. The temperature of the two plates can be obtained from a calibration curve (see Figure 79). The operational procedure is as follows. The scanner mirror when rotating sees the scene, one plate, the back of the scanner, the next plate, the scene and then, the cycle is repeated for each revolution of the scanner.

Two traces, one for each the cold and the hot plates are collected on the analog tape along with the data from the scene. Upon playback, these two traces appear as two narrow continuous strips along the side of the imagery strip. At the end of each imagery strip, there is a calibrated grey scale which corresponds to the grey levels used during the playback. The density of the grey scale levels is measured and by knowing the temperature and the transmission density of the two calibration plate strips, the density curve for the grey levels can be transformed into a density-temperature curve (see Figure 80). Three assumptions are made: (1) there is perfect linearity for the thermistor resistance-temperature calibration; (2) there is a linear relationship between the density and the temperature, in other words, only the linear portion of the dynamic range is used; and (3) the detector does really measure the

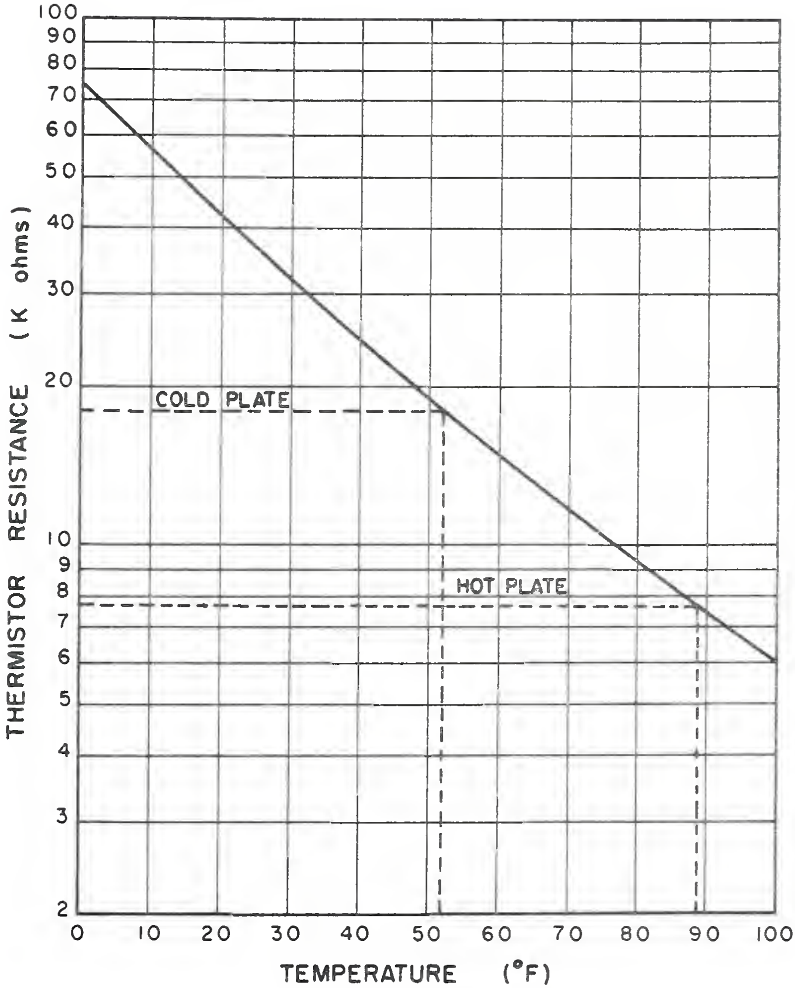


FIGURE 79. SCANNER PLATES TEMPERATURE CALIBRATION CURVE

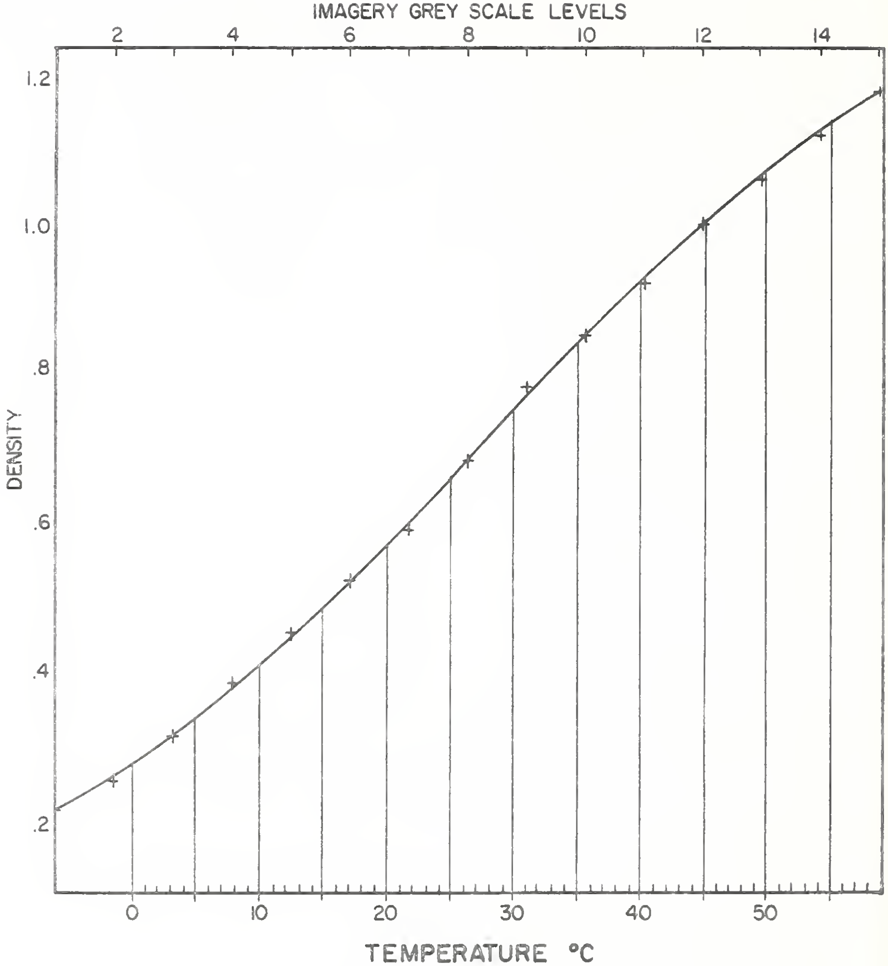


FIGURE 80. TEMPERATURE MEASUREMENTS OF INFRARED 8–13.5 MICRON IMAGERY

temperature of the resolution patch it "sees".

The first two assumptions are reasonably valid (refer to Figures 79 and 80). The third one is valid on the basis of principles of infrared technology [107, 132].

An attempt was made to measure on the 8-14 micron imagery strip the temperature of test sites for which the ground temperature was obtained at the time the imagery was collected. The ground temperatures were collected with both a Barnes PRT-4 portable radiometer and with glass thermometers. The temperatures on the imagery were obtained by measuring the transmission density at the site identified and located on the imagery. The instrument was read using the one millimeter size opening. This represented on the ground a circular area with a diameter of approximately 47 feet at imagery scale of 1:14,400.

These results, under the present scanner operational conditions, are not sufficiently accurate for engineering soils mapping purposes. This can be explained for two reasons: (1) the playback of this imagery was made for the purpose of producing the best contrast possible for soils. For this reason and for keeping the imagery within adequate distortion limits, only a certain percentage of the scan lines were played back on the cathode ray tube (otherwise the fields, for instance, become distorted beyond recognition), (2) also the densitometer opening (1 mm.) was quite large and the measurement represented an area larger than the ground test site. Part of the discrepancies are explained by the difference in time between the two sets of measurements. The results are given in Table 10. With the imagery provided in this study and with the densitometric equipment available, the measurements are not considered sufficiently accurate

TABLE 10

TEMPERATURE MEASUREMENTS BY DENSITOMETRY
ON THE 8-14 MICRON IMAGERY

Test Site No.	Density	Calculated Temperature (°C)	Radiometer Temperature (°C)	Field Temperature (°C)
6	0.58	20.7 (12:15)	23.8	23.0 (11:14)
7	0.52	17.4 (12:12)	35.7	31.5 (11:38)
8	0.53	18.0 (12:12)	31.8	31.5 (11:40)
9	0.38	7.0 (12:12)	27.8	27.0 (11:44)
10	0.36	6.8 (12:12)	25.7	25.5 (11:50)
22	0.44	12.4 (12:09)	26.8	20.5 (12:44)
23	0.46	13.7 (12:09)	27.8	25.0 (12:42)
24	0.49	15.6 (12:09)	24.6	28.5 (12:38)
26	0.36	6.8 (12:08)	21.6	25.0 (12:54)

Note: The numbers in parenthesis are the time (hours:minutes) at which the imagery and the ground measurements were taken, on April 28, 1967. In this case, only the low altitude imagery film strips were used.

for differentiating soil conditions related to thermal affects. The best thermal resolution achieved under these circumstances was 3.1°C and the mean for the nine test sites was 14.1°C.

4.64 Automatic Classification of Multispectral Digitized Data by Computer

A system of computer programs have been developed over the past three years by the Purdue University Laboratory for Agricultural Remote Sensing (LARS) for purposes of analyzing remote multispectral data for various agricultural applications, such as, automatic crop species identification and mapping, automatic soil mapping, crop moisture and disease studies and other related agricultural applications.

This research effort and the concept of a Laboratory for Agricultural Remote Sensing was developed by the National Aeronautics and Space Administration (NASA) in conjunction with the U. S. Department of Agriculture. Its purpose is to serve as a focal point for research into the applications of modern remote sensing techniques for the benefit of national and world-wide agriculture [127].

The objective in using two of LARS computer programs, LARSYSAH and LARSYSAA, was to see if the automatic classification procedures originally developed for agricultural purposes could also yield useful results in terms of engineering applications to soil mapping. These programs and LARS computer facilities were made available to this project in exchange for the use of the Highway-37 multichannel data by LARS. In this manner the LARS capabilities were made available to this JHRP project to investigate the potential of such computerized automatic classification approach for engineering applications. It was not meant to be an exhaustive

examination of all the subtleties of the LARS computer programs but to assess whether or not this approach offers promise for engineering soil mapping and still maintain as a final output the engineering significance that engineering soils maps have.

The LARS programs that were used are summarized on Figure 81. The approach is a spectral pattern recognition technique in which training samples are used as a basis for the classification. Through the use of these training samples, the computer is "trained" to recognize all areas having similar spectral signatures and to automatically classify these unknown areas into one of the categories of surficial material designated by the researcher [40, 129, 130, 131].

The first one of these programs is intended to reproduce the multispectral data on computer printouts roughly similar to the imagery film strip. The imagery grey levels are represented by printer characters. This first program also produces histograms of the grey levels for each band.

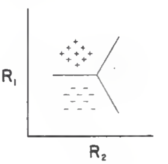
One or several bands of the grey scale printouts can be used to select training samples. They may also be used to produce desired enhancement effects in each channel by utilizing specific printer characters (letters, numbers and/or symbols) instead of using the usual histogrammed approach. This may have a desirable effect as an enhanced version of the imagery may result. Although feasible, this is a more difficult approach which may require several attempts in order to reach a particular enhancing effect. Normally the grey scale printouts are used for the location and selection of training samples only.

LARS COMPUTER PROGRAMS FOR AUTOMATIC MULTISPECTRAL INTERPRETATION

PICTOUT — FOR GREY LEVELS PRINTOUT OF EACH SPECTRAL BAND DESIRED, PRINCIPALLY USED FOR SELECTION OF TRAINING SAMPLES

LARSYSAA

- **$ STAT** — STATISTICAL analysis of spectral response of training samples and classes — histograms, spectral curves, mean vector, covariance and correlation matrices are generated.
- **$ SELECT** — SELECTION of optimum features for classification.



- **$ CLASSIFY** — CLASSIFICATION of each element of the data.
- **$ DISPLAY** — DISPLAY of classification by means of appropriate symbols with the use of threshold levels. Performance value

FIGURE 81 COMPUTER PROGRAMS DEVELOPED AT THE PURDUE UNIVERSITY LABORATORY FOR AGRICULTURAL REMOTE SENSING FOR THE CLASSIFICATION OF SCANNER DATA.

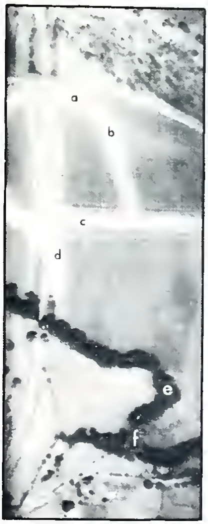
Training samples should be conceived of as a set of spectral data, representative of a given ground object or ground feature and identified on the computer printouts by a system of coordinates assigned to each scan line of scanner data. The material represented by a set of training samples is referred to as a "class".

This concept is illustrated on Figure 82 which shows an area on an airphoto, an enlargement of infrared imagery film strip and its corresponding PICTOUT computer printout. Training samples are indicated by rectangles or squares. Training samples "a", "b", "c" and "d" are representative of a class, in this case, the class is "bare soil" on a road and embankment under construction. Training samples "e" and "f" represent a second category composed of trees only. As many classes as desired can be defined as needed.

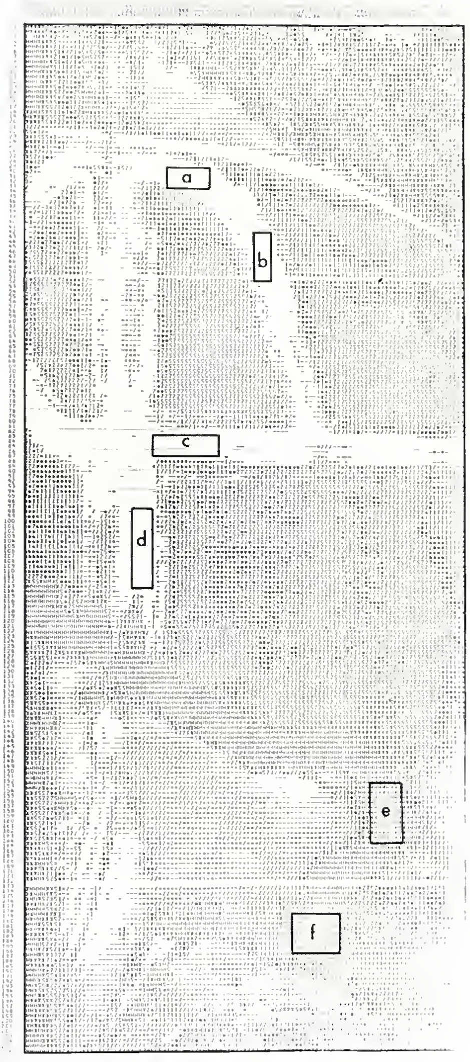
It is very important that the training samples have characteristics similar to the ones for that class of material that the researcher is interested in (see also Hoffer 1968). The grey scale printouts normally used for training samples selection would be the ones which would best show maximum difference for the objects under study.

So, the overall procedure can be summarized in these terms. After the analog to digital conversion (ADC), the digital tapes are ready to be analyzed and the first step is to obtain a pictorial printout or a grey levels map through the use of PICTOUT. Then sets of training samples are selected; as many sets are required as there are classes of objects to be analyzed. This selection of the training samples is most critical for the classification to be successful. This is where all available information such as field information collected at the time of flying

a- B-W AIRPHOTO (visible range)
scale 1 6000



b- INFRARED IMAGERY (8-13.5μ)
scale 1:3000



c- COMPUTER PRINTOUT of IMAGERY
scale 1:1500

FIGURE 82 COMPUTER PRINTOUT AS OBTAINED FROM PROGRAM PICTOUT AND ILLUSTRATING TRAINING SAMPLES.

and aerial photographs, particularly, color aerial photographs are most useful. The success of this phase is also based on the researcher's experience in his particular field of activity; pedology, forestry, agronomy, civil engineering or others. The available field information, multispectral classification techniques and the researcher's background constitute the basis of proper significant and useful selection of training samples.

The second main program utilized in this project is called LARSYSAA. This central monitor program is subdivided in a set of supervisor programs and four processor programs as is illustrated on Figure 83. This figure illustrates the procedure of multispectral data classification.

The theory and development of LARSYSAA is discussed in the literature by Swain et al. [237], Landgrebe et al. [129], Landgrebe et al. [130] and in LARS Information Note 101866, Min et al. [173]. Since the purpose of this section is principally to discuss the engineering applications, the theoretical aspects and implementation are not discussed further.

Once the training samples are selected and their coordinates (lines and rows) are punched on appropriately formated cards, the statistics are obtained on the reflective characteristics of each class. The statistics include the mean vector of each class and the covariance and correlation matrices. Histograms of each sample and/or class and their spectral response graphs can also be printed out at this time to help the researcher in his analysis of the data. Options are available either to obtain all this information in terms of each sample in each class, each class or both samples and classes. The results from the statistics allow the researcher to verify the quality of each training

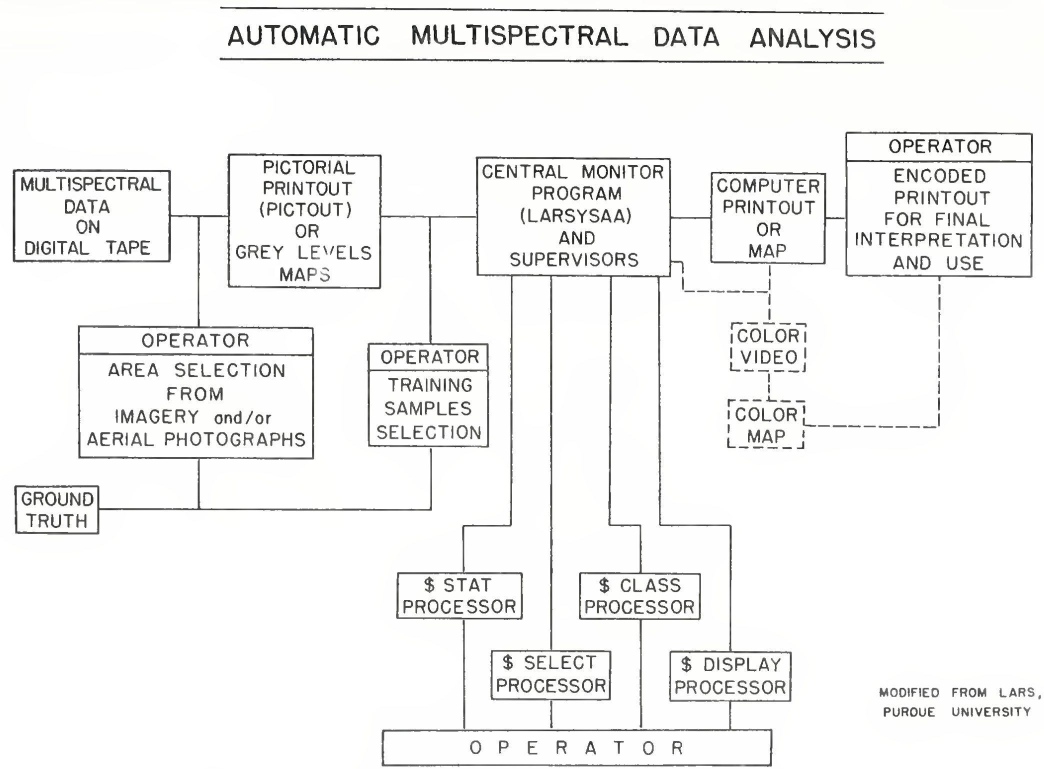


FIGURE 83 AUTOMATIC MULTISPECTRAL DATA ANALYSIS SYSTEM IN OPERATION AT 'LARS' WITH FUTURE POSSIBLE IMPLEMENTATION INDICATED IN DASHED LINES.

sample and for each class. If improvement is desired, it can be performed at this point by a re-selection of better training samples. Otherwise the next step is undertaken. Note that an option in $ STAT allows one to obtain a set of punched cards for the statistics computations which enables one to momentarily interrupt the job and re-enter later at another level of the processor. This applies to any of the four processors of LARSYSAA, as long as the statistics deck of punched cards is saved. This provides for extremely great flexibility.

Figure 84 illustrates the statistical results obtained for three classes: sand, medium dark soil and muck. The tables at the top row of this figure give the mean, standard deviation covariance matrix and correlation matrix for each class. The three graphs on the second row of this figure illustrate the spectral plot of the mean plus and minus one standard deviation for each training class.

The vertical scale is in relative intensity units. They represent the relative intensity response of the signal as digitized. These graphs show the variation of the spectral response within each wavelength band for each material. Differences in response in at least one wavelength band for each material of interest is fundamental to the classification of the multispectral scanner data. Note that there is no meaningful relationship between the response of a particular material in the different wavelength bands.

The sets of histograms on the third row of Figure 84 indicates the importance of excellent training sample selection. Point A on this figure indicates a large spread of the relative response in the signal for sand in channel 5 (or the 0.50-0.52 micron band). This is an indication that the classification using that band may be a bit less

LABORATORY FOR AGRICULTURAL REMOTE SENSING
PURDUE UNIVERSITY

HIGHWAY 37 ENGINEERING SOILS MAPPING BY MARK G. JANUARY 6

SAND

THE COVARIANCE AND MEAN FOR TRAINING CLASS SAND

	0.40-0.44	0.44-0.46	0.46-0.48	0.48-0.50	0.50-0.52	0.52-0.55	0.55-0.58	0.58-0.62
MEAN	173.89	172.01	181.46	178.13	108.00	113.13	100.38	74.14
ST. DEV	5.20	5.04	4.47	4.76	15.13	13.11	13.75	9.61

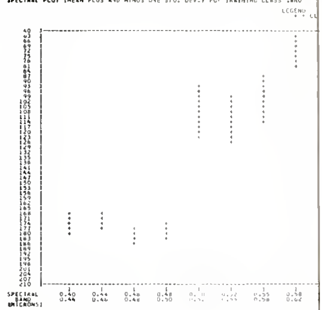
COVARIANCE MATRIX

0.40 - 0.44	0.44 - 0.46	0.46 - 0.48	0.48 - 0.50	0.50 - 0.52	0.52 - 0.55	0.55 - 0.58	0.58 - 0.62
27.06							
19.03	25.40						
19.81	18.78	20.01					
16.41	22.12	17.05	22.82				
65.16	60.23	62.91	52.77	228.99			
55.93	54.48	54.45	50.05	184.13	171.98		
48.95	64.30	51.09	61.50	182.31	142.71	189.04	
32.96	33.78	35.83	30.59	118.63	119.25	89.18	88.41
80.80	70.45	80.82	64.28	204.80	170.44	193.23	103.21
68.13	66.86	69.44	64.13	233.55	212.23	187.53	136.03
41.20	45.58	41.48	41.08	139.80	113.57	126.16	68.39
22.96	21.36	22.38	19.24	78.89	68.40	58.37	44.26

CORRELATION MATRIX

0.40 - 0.44	0.44 - 0.46	0.46 - 0.48	0.48 - 0.50	0.50 - 0.52	0.52 - 0.55	0.55 - 0.58	0.58 - 0.62
1.00							
0.73	1.00						
0.85	0.83	1.00					
0.66	0.92	0.80	1.00				
0.83	0.79	0.93	0.73	1.00			
0.82	0.82	0.93	0.80	0.93	1.00		
0.68	0.93	0.83	0.94	0.78	0.79	1.00	
0.87	0.71	0.85	0.68	0.83	0.88	0.89	1.00
0.73	0.87	0.84	0.84	0.89	0.81	0.87	0.88
0.78	0.81	0.92	0.80	0.91	0.96	0.81	0.85
0.70	0.80	0.82	0.76	0.81	0.76	0.81	0.84
0.76	0.73	0.86	0.70	0.90	0.80	0.71	0.81

SPECTRAL PLOT (MEAN PLUS AND MINUS ONE STD. DEV.) FOR TRAINING CLASS SAND



HISTOGRAM FOR ... SAND

CHANNEL 4 0.48 - 0.50 MICRONS
EACH * REPRESENTS 2 POINT(S).

CHANNEL 5 0.50 - 0.52 MICRONS
EACH * REPRESENTS 1 POINT(S).

CHANNEL 6 0.52 - 0.55 MICRONS
EACH * REPRESENTS 1 POINT(S).

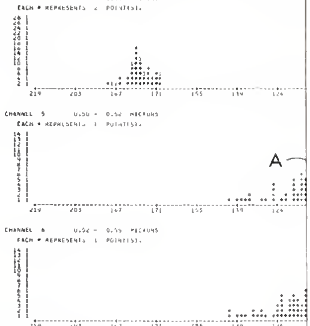


FIGURE 84.

sample and for each class. If improvement is desired, it can be performed at this point by a re-selection of better training samples. Otherwise the next step is undertaken. Note that an option in $ STAT allows one to obtain a set of punched cards for the statistics computations which enables one to momentarily interrupt the job and re-enter later at another level of the processor. This applies to any of the four processors of LARSYSAA, as long as the statistics deck of punched cards is saved. This provides for extremely great flexibility.

Figure 84 illustrates the statistical results obtained for three classes: sand, medium dark soil and muck. The tables at the top row of this figure give the mean, standard deviation covariance matrix and correlation matrix for each class. The three graphs on the second row of this figure illustrate the spectral plot of the mean plus and minus one standard deviation for each training class.

The vertical scale is in relative intensity units. They represent the relative intensity response of the signal as digitized. These graphs show the variation of the spectral response within each wavelength band for each material. Differences in response in at least one wavelength band for each material of interest is fundamental to the classification of the multispectral scanner data. Note that there is no meaningful relationship between the response of a particular material in the different wavelength bands.

The sets of histograms on the third row of Figure 84 indicates the importance of excellent training sample selection. Point A on this figure indicates a large spread of the relative response in the signal for sand in channel 5 (or the 0.50-0.52 micron band). This is an indication that the classification using that band may be a bit less

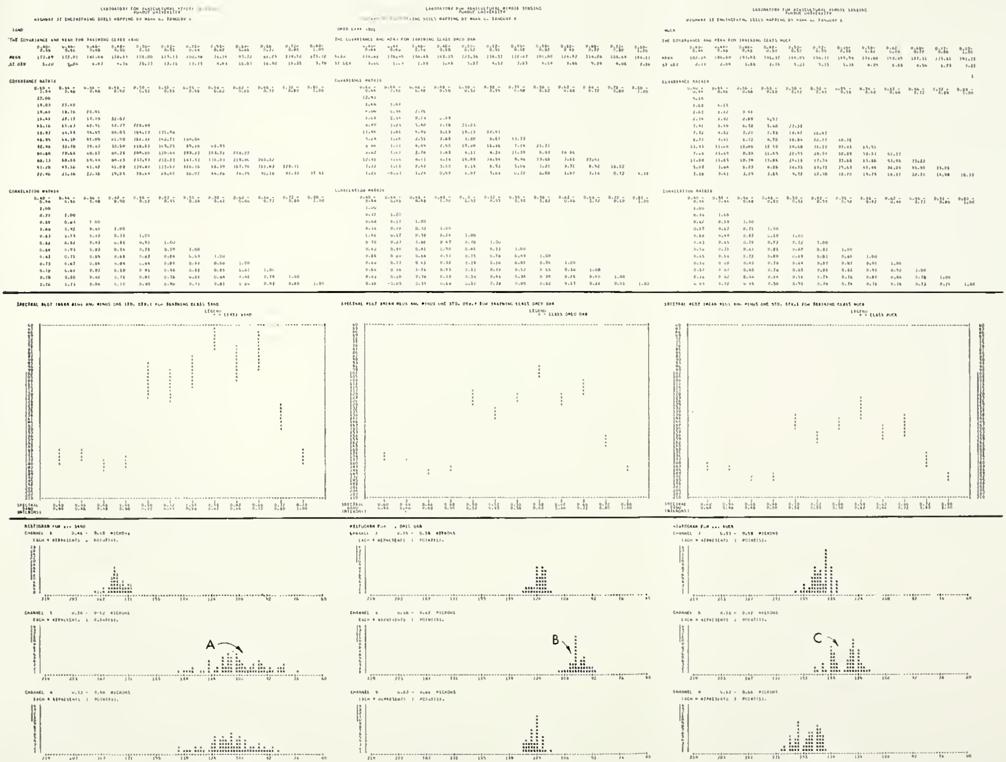


FIGURE 84. EXAMPLES OF STATISTICAL RESULTS FROM LARSYSAA SYSTEM.

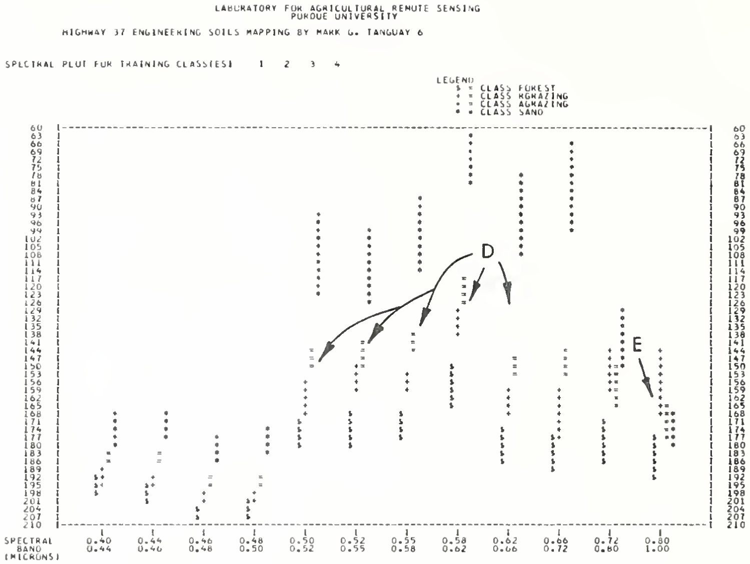
accurate than if band 4 was to be used. The horizontal scale here corresponds to the vertical scale of the spectral plots immediately above and again it is expressed in relative intensity units.

Ideally, the histogram should be narrow at the bottom, indicative of a sharp, neat and hopefully characteristic reflectance in that channel, for that particular material. This is the case illustrated by the letter B.

Another case is illustrated in C where the response distribution is bimodal. This bimodal histogram is indicative of an imperfect training sample selection; in other words the ground materials corresponding to this class contained two spectral groups or two surface conditions of muck. Most likely one was wetter than the other. Training sample selection can be improved until a purer class is obtained. This would remove the bimodal distributions of reflectance as shown above, and could result in a better and a more significant classification.

In order to see if the classes utilized in the statistical phase are easily separable or not, an option permits the printing of a series of combined or coincident spectral plots for the training classes. Figure 85 illustrates the case where eight classes are distinguishable. In the upper half, point D indicates that the four classes would be equally well distinguished in the five bands indicated by the arrows. But in the 0.80-1.00 micron band, the last three classes would be mixed (point E) and most particularly what is classified as "class AGRAZING" would be most difficult to distinguish from "class SAND".

In the lower half, point F indicates that two classes are most difficult to distinguish in the 0.66-0.72 micron band. The "class LLSILT"



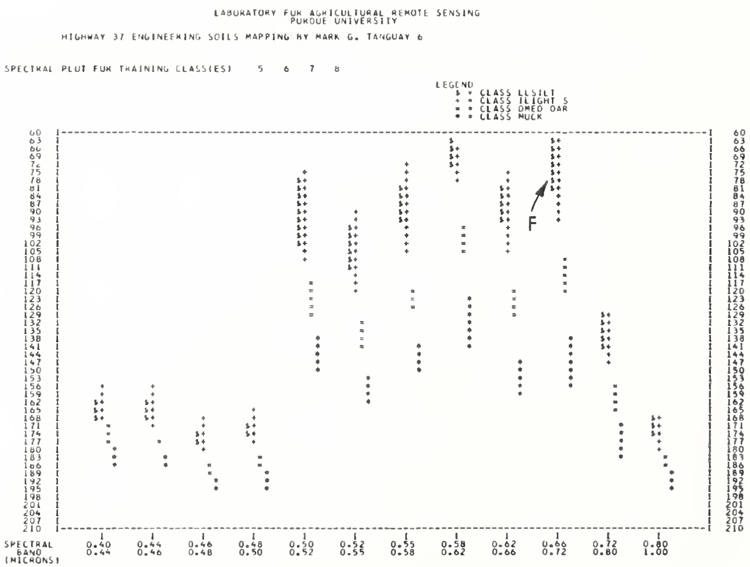


FIGURE 85 SPECTRAL PLOTS FOR EIGHT CLASSES.

(for very light tone silt) has the same intensity response as the "class ILIGHTS" (for intermediate light silt) in that band but the other two classes have lower intensity responses and can be distinguished. In other words these two could be classified easily. By visual inspection it is found that, in all spectral bands, these two classes, LLSILT and ILIGHTS, have similar intensity response. It is thus seen that they do have a similar spectral response and accordingly, the training samples for these two classes could be grouped under one class, because they probably would not be classified easily into two significantly different classes, with only these 12 bands being used.

This figure can be used also to indicate by visual inspection what bands are most likely to produce a better classification of the multi-channel data.

A much faster and more sophisticated way of finding a more dependable answer as to what bands should be used in the classification is to use $ SELECT. The theory and procedures are explained in several LARS publications (Cardillo and Landgrebe [40], Min [173], Landgrebe et al. [129]. Fundamentally the selection of optimum bands are based on the degree of spread between the classes and the variation within the class response for all possible combinations of the different bands.

This step is followed by the classification ($ CLASS). Each data point in the entire flight line is classified into one of the classes that were determined by the researcher and for which training classes were established. Each data point is classified into the class for which it has the highest probability of belonging. But the probability of belonging to that class may or may not be very high. For example assume

the researcher established three classes and obtained training samples for vegetation, soil or water.

Each point of data must be classified into one of these three classes, and a probability of belonging to that class is also calculated. The piece of data which may actually correspond to a car may not appear spectrally to belong to any one of these three classes but in fact it must be put in one of the three. Because of the low probability of belonging to any of the established classes, the point can be "thresholded," and thereby avoid an erroneous classification, but thresholding will be discussed later. This stresses the importance of having significant classes and of properly using the thresholding option in the display. The classification results are then stored on assigned magnetic tapes for easier retrieval.

The next sequence is to display the information. $ DISPLAY provides for this, in assigning to each class a selected set of printer characters for output printing, and obtaining a map of the classification results as well as a tabular display of the performance results. These characters are determined by the operator (researcher). A judicious set of printer characters helps emphasize the desired classes of materials.

Figures 86 to 90 are examples of automatic multichannel data classification. They indicate potential applications for engineering soil classification. Figure 86 is a set of six maps and a photo-mosaic for Area 1-A. These printouts were produced by using the 12-channel scanner data digitized by LARS. The 12 channels include all the visible and the reflective infrared bands from 0.4 to 1.0 micron. They do not include the ultraviolet band which was obtained by a different scanner system in

FIGURE5) (6) THRESHOLDING.

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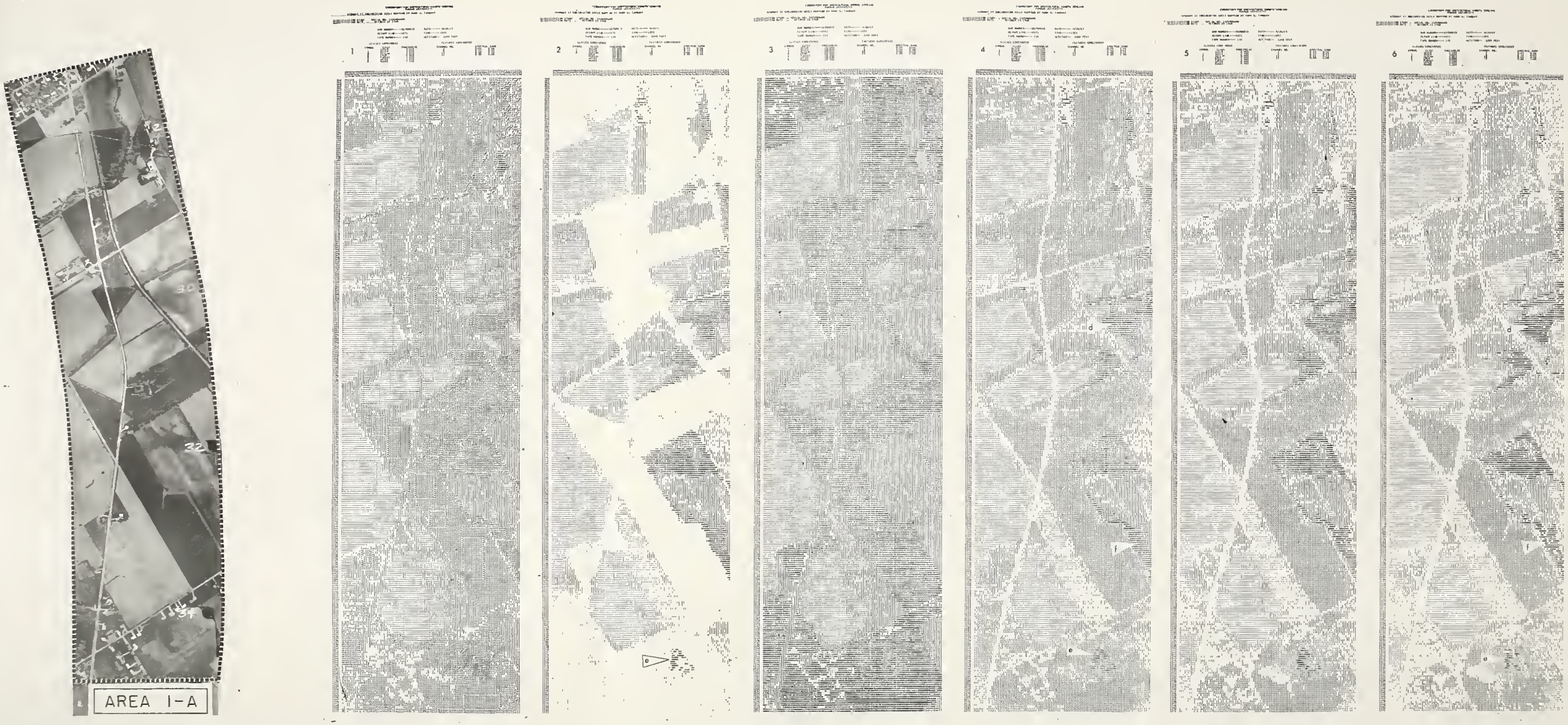

FIGURE 86. LARSYSAA PRINTOUTS FOR (1) GENERAL CLASSIFICATION, (2) THREE SOILS, (3) SOILS, CROPS, FOREST AND ROADS, AND (4) (5) (6) THRESHOLDING.

The University of Michigan aircraft. Nor do these 12-channel data include the thermal infrared and for the same reasons.

A total of twelve test areas were selected prior to working with the LARS automatic classification techniques. Six of these areas were more extensively studied with the computer approach. Results are included for five of these six areas. These areas are also shown on Plates 1 to 5 in Chapter 3.

Map 1 on Figure 86 is a general classification of all seven classes for area 1-A, as they are defined at the top left: three classes are for three different soil conditions and one each for crops, forests, water and roads. Map 2 indicates the soils areal distribution only. It shows where the light toned soil (SOILD) is located, where the medium dark soil (SOILW) is located and where the wet and dark soil (SOILWW) is located. It is of engineering importance to see that Map 2 can readily show the distribution of the dark wet ground. The ground conditions attached to each soil class here were verified in the field ground truth collection. This last soil class corresponds to a soil type that would require special treatment (removal or extra drainage), if an engineering facility was to be developed. The printer character letter M helps to enhance the distribution of this poor quality soil and permits the location of the potential trouble areas very rapidly.

Map 3 is a general interpretation of all the data except that it shows a different enhancement most useful to locate the classes of materials. Maps 4, 5 and 6 illustrate the effect of different threshold levels. The use of thresholds is made possible in the $ DISPLAY processor in order to be more or less restrictive on the display of the data.

By using a low threshold level, all the data points that may have some spectral resemblance to each class, however broad this resemblance may be are shown. If a high threshold level is used, the effect is more restrictive and only the data points having very close spectral resemblance are displayed. A low threshold value is useful to display, in this case, all the light tone soils of an area that may slightly vary in spectral signature but are similar for engineering purposes. On the other hand, a high threshold value is useful to locate potentially troublesome areas with much greater precision, as is the case for the SOILWW class. This is illustrated on maps 4, 5, 6 of Figure 84 by the letter "f" which indicates that this area of SOILWW does not have the same significance as area "d"; this is revealed by the greater number of blanks that appear in this area, as the threshold value is increased.

A most important feature on this set of maps is a muck pocket in the lower third of the map, indicated by the letter "e". No training sample was taken yet it is classified in the class for adverse soils (SOILWW). This emphasizes the latent interpretative power of this automatic classification based on spectral reflectance but also the need for ground truth collection.

The maps of Figure 87 show two other potential uses of this approach. The printout on the right side (map 2 for Area 2) shows bare soils of critical engineering significance. The areas designated with the plus sign symbol (+) indicates the upper ground of the kame moraine in this particular section along Highway-37. This ground is underlain by sands and gravels as revealed by ground checking. It then appears that potential applications for location of granular materials could be realized

AREA 2

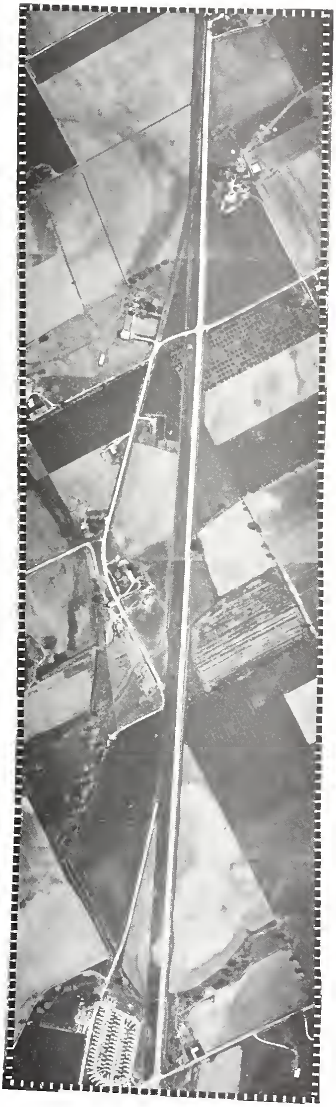

FIGURE 87. PRINTOUTS (

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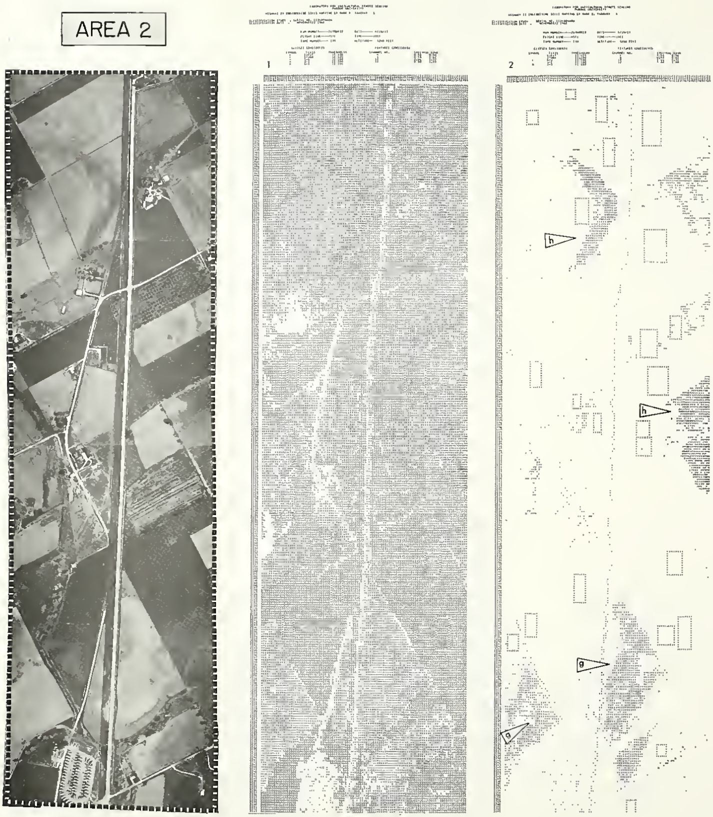

FIGURE 87. PRINTOUTS OF AN ATTEMPT TO DELINEATE TWO MAJOR SOIL TYPES.

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under certain circumstances, as is the case for locations marked with a "g", on map 2, Area 2.

Another case of locating adverse ground condition is illustrated on this map by the letter "h". It shows a meander scar filled with highly organic wet soil as revealed by ground truth. This depressional soil condition would require special treatment or should be avoided altogether. It is emphasized here by the letter M and by blanking out all other soils except for the upper parts of the kame moraine indicated by the plus sign (+).

Figure 88 is a special case where the approach in mind was to classify the soils in terms of their spectral response as related to the land forms. The result was partially successful but it is in fact most indicative. If a relationship can be established between land form and spectral responses of its corresponding materials, then the land form parent materials relationship used in photo-interpretation would be valid here too. The inference is that results from it could be most beneficial. The impact in determining soil textures would be tremendous.

In Figure 88, the upper two fields "S" and "T" belong to the ground moraine terrain (Km) indicated by the mottled tone on the photo-mosaic. The lower field "Q" belongs to the flood plain (Fp) and is more uniform in tone. The automatic classification results are shown in map 2, Area 3, and the difference in interpretation as outlined corresponds to the area included between the dash line and the full line. This area actually should be classified as flood plain but is classified as material that belongs spectrally to the ground moraine. This discrepancy is attributed to possibly two things; the materials from the upland (ground moraine M_k),

AREA 3

FIGURE 88 PRINTOUTS OF
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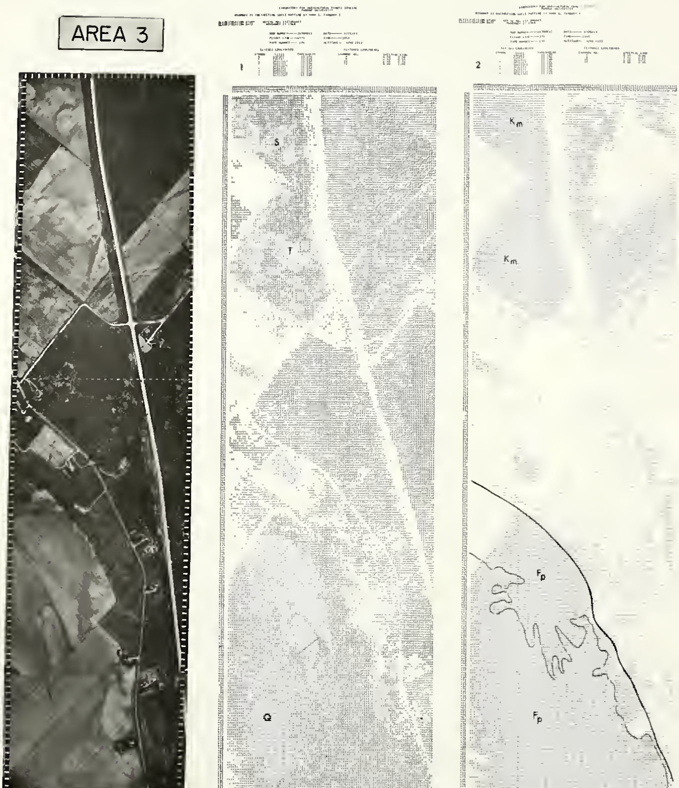


FIGURE 88 PRINTOUTS OF AN ATTEMPT TO DELINEATE LAND FORMS ON A SPECTRAL RESPONSE BASIS.

are washed onto the flood plain by conventional geomorphologic agents like rain, running water, etc., or the thin windblown silt mantle that covers the area masks the true land form borders, spectrally speaking.

The main point here is that spectral responses for broad classes of materials may possibly be related to land forms. And the indications of this justify further research on other ground conditions and land forms of other areas.

Figure 89 is a case in which drainage features of an area are evidenced by the automatic classification of the imagery. To appreciate these features, a close comparison should be made with the photo mosaic. All the areas represented by the character "H" on the left hand computer printout correspond to drainage ways or very wet areas. Examples of this are shown by features on both the printout and the photos by letters "a" and "b". Item "c" corresponds to a corner of dryer ground in that bare field. This was revealed by a very close examination of the color and color infrared airphoto. Item "d" corresponds to the right half of that field which was very wet at the time of flying (see airphoto). Item "f" corresponds to a meander scar on the White River flood plain; it also corresponds to wet ground. This figure indicates how detailed the automatic classification can be with proper training samples selection. It indicates that minute features of engineering significance such as areas requiring special drainage or containing poorly drained soils can be automatically located by this method and can be delineated by a judicious selection of printer characters.

Figure 90 presents five computer printout maps for a selection of the Martinsville by-pass at the time of its construction. Map 1 is the

AREA 5

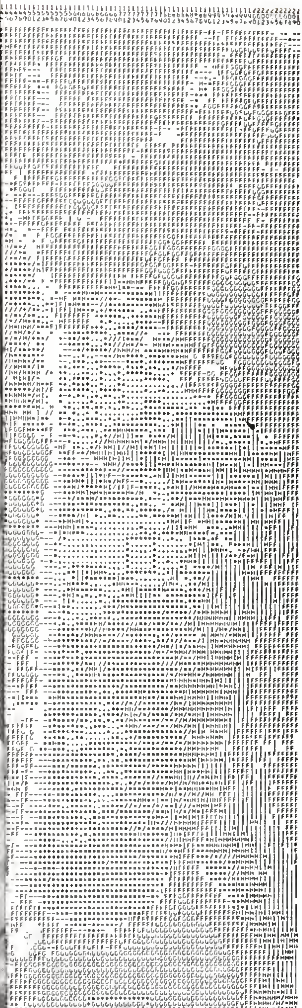
ICULTURAL REMOTE SENSING
UNIVERSITY

RUN G. TAIGUAY 5

DATE------ 4/28/67
TIME------1059
ALTITUDE-- 3200 FEET

FEATURES CONSIDERED

DS CHANNEL NO. SPECTRAL BAND
2 0.44 0.46
10 0.66 0.72
12 0.80 1.00



FIGU

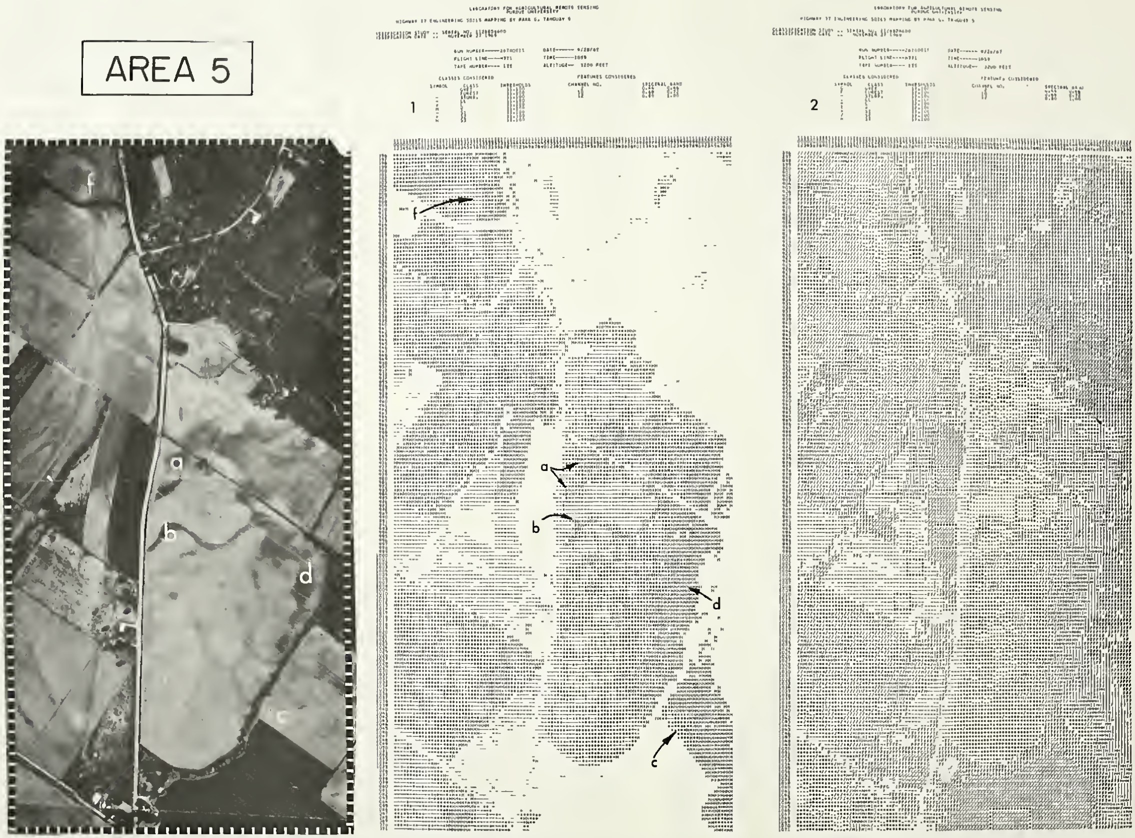


FIGURE 89 PRINTOUTS OF SOILS AND DRAINAGE EFFECT.

FIGUR

AREA 6

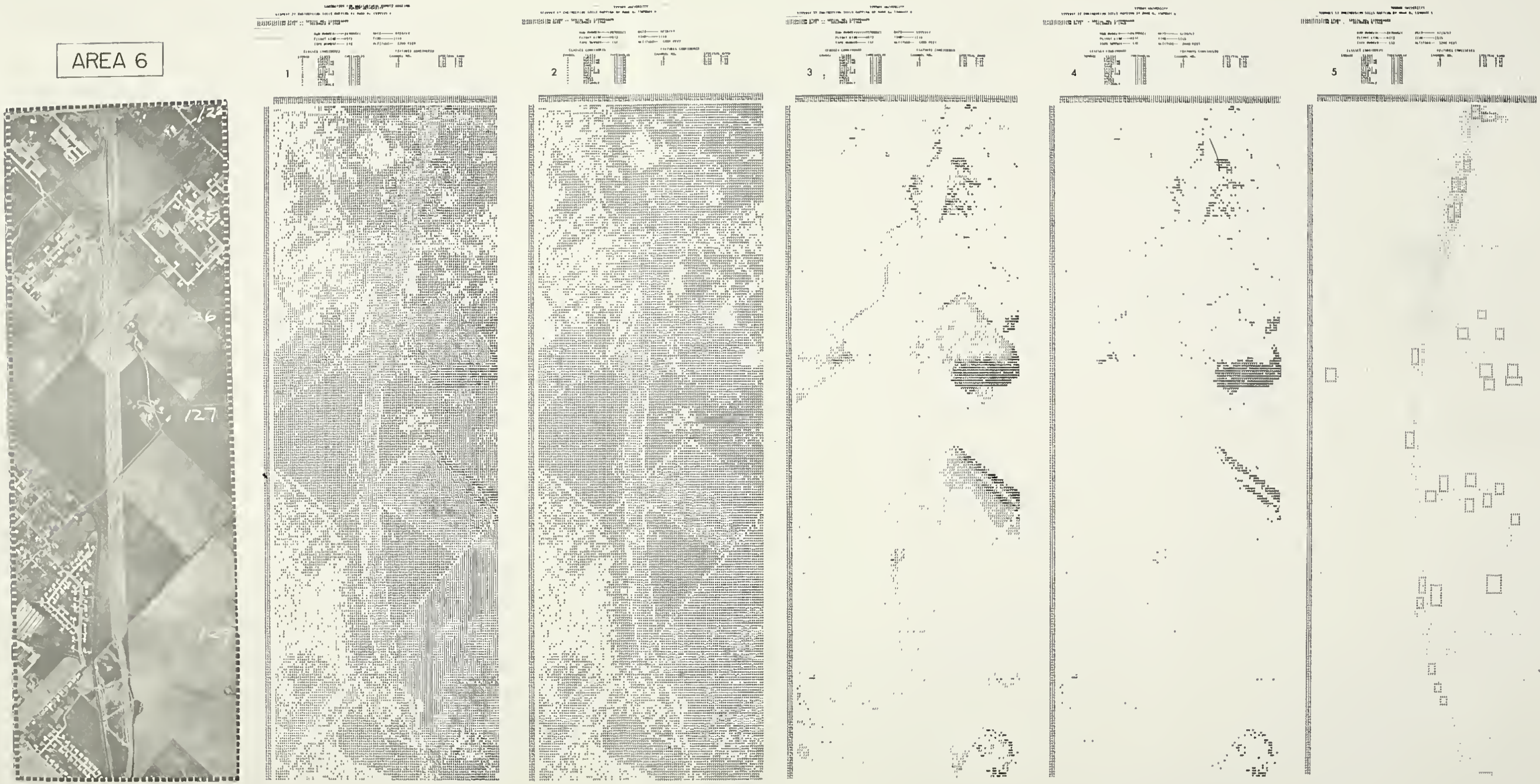


FIGURE 90 PRINTOUTS OF (1) GENERAL CLASSIFICATION, (2) LAND USE AND SOILS, (3)(4) MUCK AREAS, AND (5) SAND.

general classification of the earth materials and the vegetation into eleven different classes. Map 2 indicates the bare soils versus the vegetation; this permits us to readily know where bare soils are and the amount of interference by the vegetation.

Map 3 is significant for engineering purposes: it locates very rapidly the two soils that are troublesome in the area. The area contained several muck pockets and areas of dark tone wet soil not as deep as the muck but still sufficiently wet to require either drainage or removal. The muck is shown by the letter M and the dark wet soil by slashes. The distortion effect is quite obvious here but it does not prevent the spectral data to be interpreted properly. This is another case indicating the need of good aerial photography to be taken simultaneously to the multispectral data.

Map 4 indicates only the muck which was thought to be more critical and should receive special attention in an engineering project. This is why it was separated.

Map 5 shows an interesting feature. The materials used to build part of the by-pass were coming from the ridge moraine just north and served as a fill between the higher ground (ridge moraine) and the lower ground shown on this map (outwash and lacustrine plain). This section of the fill and only this section of the fill which used the sands and gravels of the ridge moraine appears very clearly on Map 5. It was shown for the purpose of indicating how selective and accurate this method of automatic classification based on spectral signatures can be. Note the location of the training samples (asterisks). Note that along the by-pass training samples were selected all the way from the north end to

the southern end (bottom of map) and yet only the northern most area shows the presence of sand (dots). This is an extremely important point. No type of airphoto can detect something of that nature. Even the color airphoto could not tell this because there was not enough color contrast between the sand of the upper section and the silty ground of the southern section. This indicates that materials can be classified automatically according to their color and that they may be classified in terms of their texture if a minimum of ground information is available.

The computer time involved in producing these maps as illustrated is relatively low. To answer a first question each of the 5 maps in Figure 90 take an average of about 2 minutes each or 10 minutes for a package of five maps. The interpretation of color photographs for exactly the same area took one hour and 15 minutes. For the black and white photographs it took two hours. These values however should not be compared directly.

In fact the computer time including the use of PICTOUT for the training samples selection, the training samples selection itself and the time for using LARSYSAA amount to more than just the few minutes mentioned above.

For Area 1-A, the total time for producing nine computer printer maps (5 of which appear on Figure 86) was three hours. The breakdown is:

15 min.	grey level maps from PICTOUT for 3 bands
1 hr.15 min.	training samples selection (57 samples, 7 classes)
15 min.	punching cards
1 hr.15 min.	LARSYSAA time, including classification with four channels and display on 9 printouts.
3 hrs.	total time

A similar case was Area 6 where 11 printout maps and 11 classes were studied which took a total time of two hours. The classification was done using four channels here too, but the operator had gained more experience and every instant on the computer was made as productive as possible. Also the time for training samples selection was kept to a minimum, even if a total number of 44 samples were used for the 11 classes.

These figures can be compared with the photo interpretation time mentioned above. The two hour interpretation time of black and white photos is equivalent to the two hours of training samples selection and computer time which in turn compares fairly well with the one hour 15 minutes for the color photos interpretation, considering the selectivity that each printout map can introduce. The important point is that for much larger areas the gain in time using the automatic classification would be very large, while here for a small area it is about even with the standard PI time.

It must be clearly stated at this point that the computer facilities at LARS are not considered to be the fastest. They are used as a research system which will be continuously improved. In fact the system is using a 600 line printer, while printers two to three times as fast are available. The present hardware at LARS also uses a single disc pack and three 9 track tape units operated at 60 KC [127]. A sensible gain in time will be realised when the LARS hardware will be improved by the addition of a second disc pack, by the increase of tape units speed to 90 KC and by the increase of memory size from 16 K to 32 K.

The time for training sample selection was found to be considerable. This is expected to be corrected by the use of a light pen coupled to

the hardware which would simplify the training sample selection. It would eliminate most of the card punching and would permit a more accurate and yet faster training sample selection.

The selection of imagery bands for engineering soils interpretation by the LARS system produced very useful results in terms of the optimum bands to be used. Of the 13 original areas selected, six were more thoroughly studied. For each of these six, \$ SELECT was used in order to determine what set of 2, 3 or 4 bands would perform the best classification (\$ CLASS).

The results are shown on Table 11. This indicates that when three bands only are to be used, the number 12 band (0.8-1.0 micron near infrared) is always selected, the next most useful bands were respectively band no. 10 (0.66-0.72 micron), band no. 8 (0.58 - 0.62 micron), band no. 6 (0.52-0.55 micron), band no. 2 (0.44-0.46 micron). When four bands are being used, there is a possibility for just about any combination of four bands to appear except that band no. 5 did not appear at all. Bands nos. 10 and 12 or nos. 9 and 12 always appeared, band no. 8 seemed also a frequent best choice (see also Table 6 for band nos. equivalence in wavelengths).

This indicates that for automatic classification of soils the number of bands cannot be restricted to a small number of bands and that all the bands should be considered and made available. It also corroborates quite well the conclusions of the visual imagery interpretation in a previous section that the most useful bands were no. 12 (0.8-1.0 micron), no. 9 (0.62-0.66 micron) no. 6 (0.52-0.55 micron) for engineering soils.

The \$ DISPLAY program includes an option by which a classification

TABLE 11

OPTIMUM IMAGERY BANDS FOR ENGINEERING SOIL MAPPING AS SELECTED BY $ SELECT PROCESSOR

Area	GROUPS OF BANDS		NO. OF CLASSES USED
	group of 3	group of 4	NO. total (no. for soils)
1-A	8,10,12	2,6,10,12	7 (3)
2	8,10,12	4,8,10,12	5 (3)
3	2,10,12	4,6,10,12	9 (7)
4	6,10,12	6,9,10,12	10 (7)
5	2,10,12	2,9,10,12	9 (7)
6	4,9,12	2,9,10,12	11 (7)

summary for each training sample, the overall classification performance and a summary by training classes with the average performance by training class are tabulated. Figure 91 is an example which was obtained for Area 5.

The important point is that spectral classification results by the LARS automatic system can be improved by a better selection of training samples. Table 12 summarizes how such improvements were realized for the six areas studied in greater detail, for the training classes only. The results and the computer maps produced lead one to believe that the implementation of Computer Classification Maps as engineering soils maps can be realized under certain circumstances.

It is evident that computer printouts are not easy to read even for a trained person. Most likely they could not be used by the field engineer on a project. In order to improve the presentation of the automatic classification end-result, the engineering personnel at LARS are considering the possibility of a color television display (see dashed lines on Figure 83) and some other means of producing a map easy to read, easy to use. The point here is to consider the computer printout maps as research tools for the present time.

In summary, the automatic computer classification as implemented by the LARS system and as tested in this research project on engineering soils mapping should be considered as a very important advance in automatic interpretation. This method of study revealed that the LARS system can produce, very rapidly, sets of soil maps significantly useful to the engineer. They can detect and classify areas indicating the distribution of main soil classes, drainage features, wet zones, muck pockets,

LABORATORY FOR AGRICULTURAL REMOTE SENSING
PURDUE UNIVERSITY

HIGHWAY 37 ENGINEERING SOILS MAPPING BY MARK G. TANGUAY S

CLASSIFICATION STUDY .. SERIAL NO. 1128806600
CLASSIFICATION DATE .. NOVEMBER 27 1968

RUN NUMBER-----26700011 DATE------ 4/28/67
FLIGHT LINE----H371 TIME------1055
TAPE NUMBER---- 135 ALTITUDE-- 3200 FEET

CLASSES CONSIDERED

SYMBOL	CLASS	THRESHOLDS
	GVET	11.100
	FOREST	11.100
-	STUBB.	11.100
-	LL	11.100
+	L	11.100
H	V	11.100
-	S1	11.100
+	S2	11.100
H	S3	11.100

FEATURES CONSIDERED

CHANNEL NO.	SPECTRAL BAND	
2	0.44	0.46
10	0.66	0.72
12	0.80	1.00

CLASSIFICATION SUMMARY BY TRAINING FIELDS

	CLASS	NO OF SAMPS	PCT. CORCT	GVET	FORE	STUB	LL	L	V	S1	S2	S3	THRS
				NO OF SAMPLES CLASSIFIED INTO									
2	GVET	30	100.0	30	0	0	0	0	0	0	0	0	0
3	GVET	30	100.0	30	0	0	0	0	0	0	0	0	0
4	GVET	108	100.0	108	0	0	0	0	0	0	0	0	0
9	STUB	12	100.0	0	0	12	0	0	0	0	0	0	0
10	STUB	12	100.0	0	0	12	0	0	0	0	0	0	0
11	STUB	12	100.0	0	0	12	0	0	0	0	0	0	0
12	LL	6	100.0	0	0	0	6	0	0	0	0	0	0
13	LL	9	100.0	0	0	0	9	0	0	0	0	0	0
14	LL	25	100.0	0	0	0	25	0	0	0	0	0	0
15	L	4	75.0	0	0	0	0	3	0	1	0	0	0
16	L	2	100.0	0	0	0	0	2	0	0	0	0	0
17	L	4	100.0	0	0	0	0	4	0	0	0	0	0
18	L	6	100.0	0	0	0	0	6	0	0	0	0	0
19	L	6	100.0	0	0	0	0	6	0	0	0	0	0
20	V	6	100.0	0	0	0	0	0	6	0	0	0	0
21	V	6	100.0	0	0	0	0	0	6	0	0	0	0
22	V	4	100.0	0	0	0	0	0	4	0	0	0	0
23	S1	3	100.0	0	0	0		0	0	3	0	0	0
24	S1	4	100.0	0	0	0		0	0	4	0	0	0
25	S1	9	88.9	0	0	0		1	0	8	0	0	0
26	S2	4	100.0	0		0	0	0	0	0	4	0	0
27	S2	4	100.0	0		0	0	0	0	0	4	0	0
28	S2	6	100.0	0		0	0	0	0	0	6	0	0
29	S2	6	100.0	0	0	0	0	0	0	0	6	0	0
30	S3	8	100.0	0	0	0	0	0	0	0	0	8	0
31	S3	12	100.0	0	0	0	0	0	0	0	0	12	0
32	S3	16	93.8	0	0	0	0	1	0	0	0	15	0
	TOTAL	354		168	0	36	40	23	16	16	20	35	0

OVERALL PERFORMANCE = 99.2

LABORATORY FOR AGRICULTURAL REMOTE SENSING
PURDUE UNIVERSITY

HIGHWAY 37 ENGINEERING SOILS MAPPING BY MARK G. TANGUAY 5

CLASSIFICATION STUDY .. SERIAL NO. 1128806600
CLASSIFICATION DATE .. NOVEMBER 27 1968

RUN NUMBER-----26700011 DATE------ 4/28/67
FLIGHT LINE----H371 TIME------1055
TAPE NUMBER---- 135 ALTITUDE-- 3200 FEET

CLASSES CONSIDERED

SYMBOL	CLASS	THRESHOLDS
	GVET	11.100
	FOREST	11.100
-	STUBB.	11.100
-	LL	11.100
+	L	11.100
H	V	11.100
-	S1	11.100
+	S2	11.100
H	S3	11.100

FEATURES CONSIDERED

CHANNEL NO.	SPECTRAL BAND	
2	0.44	0.46
10	0.66	0.72
12	0.80	1.00

CLASSIFICATION SUMMARY BY TRAINING CLASSES

	CLASS	NO OF SAMPS	PCT. CORCT	GVET	FORE	STUB	LL	L	V	S1	S2	S3	THRS
				NO OF SAMPLES CLASSIFIED INTO									
1	GVET	168	100.0	168	0	0	0	0	0	0	0	0	0
3	STUB	36	100.0	0	0	36	0	0	0	0	0	0	0
4	LL	40	100.0	0	0	0	40	0	0	0	0	0	0
5	L	22	95.5	0	0	0	0	21	0	1	0	0	0
6	V	16	100.0	0	0	0	0	0	16	0	0	0	0
7	S1	16	93.8	0	0	0	0	1	0	15	0	0	0
8	S2	20	100.0	0	0	0	0	0	0	0	20	0	0
9	S3	36	97.2	0	0	0	0	1	0	0	0	35	0
	TOTAL	354		168	0	36	40	23	16	16	20	35	0

OVERALL PERFORMANCE = 99.2
AVERAGE PERFORMANCE BY CLASS = 98.3

FIGURE 91. EXAMPLE OF CLASSIFICATION PERFORMANCE.

TABLE 12

AUTOMATIC CLASSIFICATION PERFORMANCE

Area No.	No. of Channels / No. of Classes	Overall Performance (%)	
1-A	2/6	1st trial	95
	4/7	2nd trial	94.8
	4/7	3rd trial	97.8
2	3/5	1st trial	86.7
	4/8	2nd trial	85.1
	4/8	3rd trial	86.9
	4/5	4th trial	92.9
3	4/9	1st trial	89.9
	4/9	2nd trial	98.9
4	4/10	1st trial	84.5
	4/10	2nd trial	95.9
5	3/9	1st trial	90.7
	3/9	2nd trial	99.2
6	4/11	1st trial	86.6

bare rock areas: however the final interpretation and overall significance has to be assessed by an engineer competent in soils interpretation.

These maps have indicated the possibility to relate spectral signature of broad soil classes to the parent land forms. This merits further research for other areas, other soils and land forms. This relationship would have a great significance in terms of automatic interpretation of soils and their textures because by an adequate grouping of training samples by land forms and spectral signatures, the basic premise used in photo interpretation which states the relationship between land form and parent material could then be used in the automatic classification also.

These maps have also shown one case in which the soil delineated could be directly related to its source, on the basis of reflectance properties: this could not be done for the same area with the use of the color airphotos only. This point also deserves further study.

CHAPTER 5

COST ANALYSIS

There is relatively little that has been published on cost comparison of aerial photography in engineering soils mapping and the benefits to the soils survey engineer. This is understandable: it is due in part to the fact that costs change rapidly and to the definite lack of enthusiasm at publishing costs information.

A few studies of airphoto costs are reported in the literature. Aguilar recently reported on cost of photogrammetric surveys [1]. Wright also reported on photogrammetric costs [260]. Chaves, Shuster and Warren report costs on color transparencies dated 1962, which were above today's cost range [42]. As a general rule Chaves and Schuster indicate that the cost of color is between two to four times the cost of black and white photography [44].

Minard indicates the gain of information achieved when using color. He quotes costs (1960) that also are above today's costs [174]. Mintzer and Sen Mathur point out the gain in interpretation time by using color in the order of 50 percent over black and white. They also give a ratio of black and white to color cost of 1.3 and they point out the reduction in field checking time of the order of 50 percent [176a]. These studies do not always integrate the photography costs within the overall costs of surveys. This has the effect of emphasizing the cost of color [227].

Moultrop (1961) indicated a price of $11.00 per square mile for engineering soils mapping on a regional basis at a scale of one mile to one inch [188].

McKittrick studied the cost of sub-surface investigations and the potential savings that could be achieved by using black and white aerial photographs. For four different case studies he indicates cost reductions of 10 percent to 22 percent of soil survey costs when using airphotos [160].

In this research project, all costs and times were carefully noted to attempt a cost analysis. The personnel of the Indiana State Highway Commission provided information on all the costs for flying, processing and printing of photographic materials and reduction and printing of the photo-maps for this study.

Interpretation times were noted by the author. Costs for field checking, sampling and drafting of maps were noted. Costs used for soil testing were those provided by personnel of the ISHC Materials and Testing Division.

Based on this information, Table 13 was prepared. It is important to note that these costs were based on the 70 mile route under study and the mapping of all or of sections of this route as was indicated before. It is based on costs for film for the period of March to April 1967. The other items are based on costs available during the period of 1967 to 1969. Note that the black and white photography (BW) at a scale of 1:20,000 was for a corridor of 5 miles in width and 70 miles long. All other photography was for single flight line strips (thus not taking into account the normal 30 percent side lap of regional coverages).

TABLE 13

COMPARATIVE COST STUDY OF ENGINEERING
SOIL MAPS OBTAINED FROM DIFFERENT AERIAL SOURCES
(in dollars per linear mile)

COST OF FOR	BW 1:20,000	BW 1:12,000	BW 1:4,800	Color Prints 1:4,800	Color Trans-parencies 1:4,800	Color Infrared transparencies 1:4,800
(1) FLYING	N.A.	0.70	1.26	1.26	1.65	1.65
(2) FILMS	N.A.	0.81	1.92	11.34	8.24	9.43
(3) CHEMICALS	N.A.	0.02	0.04	2.72	1.03	1.03
(4) PRINTS	3.76*	0.24**	0.73***	8.36***	none*** (18.00)	none*** (18.00)
(5) PROCESSING-PRINTING	N.A.	0.33	0.98	3.93	2.29	2.29
(6) MOSAICS (uncontrolled)	1.57	1.89	3.29	3.29	3.29	3.29
(7) PHOTO INTERPRETATION	2.14	2.05	11.70	8.40	8.40	8.40
(8) FIELD CHECKING AND SAMPLING	12.25	12.25	12.25	8.75	8.75	8.75
(9) SOIL SAMPLES TESTING	41.80	41.80	41.80	28.00	28.00	28.00
(10) PHOTOMAPS TRACING	4.10	4.72	6.31	6.31	6.31	6.31
(11) REDUCTION AND PRINTING	1.71	3.41	6.83	6.83	6.83	6.83
TOTAL UNIT COST	$67.33	$68.22	$87.11	$89.19	$74.79 ($92.79)	$75.98 ($93.98)

* for a 5 mile wide corridor, 70 miles long
** for a 9000' wide strip, 70 miles long
*** for a 3600' wide strip, 70 miles long
( ) additional cost when color prints are used in addition of the positive transparencies

The item "Prints" indicated in parenthesis is the additional cost of color prints from transparencies: this puts the color transparencies and color infrared above the others. The cost for field checking and sampling was considered to be 30 percent less when using color photography. This was based on the close study of the actual borings made to assist in the interpretation of the black and white film and the estimated number that could be eliminated if color photographs were used.

It is very important to note that the figures in this table should not be quoted out of their context. For instance the cost for "processing-printing" of the color prints is in fact the cost of the processing of the color negative from which the prints were made. The cost for "prints" of the color prints is the cost of materials and labor as contracted by a commercial firm. The cost for BW 1:12,000 prints is only for material; the cost for labor is included as a separate item.

Table 13 compares overall mapping costs using color and black and white at the same scale. It shows that only a very small increase in overall cost results from the use of color prints from the Ektachrome MS film negatives. The reduction in interpretation time and in amount of sampling when color is used tends to offset the higher cost of the color prints.

Following this cost study of the engineering soils maps, two sections of State Route 37 for which field soil surveys had recently been done were examined in terms of potential savings that could be realized by using engineering soils maps. For this purpose the reports of roadway soil surveys for Project F-92 (12) S. R. 37, Lawrence County, Indiana, and for Project F-63 (18), Section 11, Johnson and Marion Counties,

Indiana, were read and the plans and profiles examined in detail.

All field information such as borings, rock soundings, sampling, testing and others that were not considered pertinent in the light of the information provided by the detailed engineering soils maps, were added up and their costs computed on the basis of itemized costs obtained from the personnel of the ISHC Materials and Testing Division. The result was that for the first project (approximate length of 5.5 miles) an estimated reduction in cost of $946.00 per linear mile would have resulted. This is more than ten times the cost of preparing engineering soils maps by competent engineers trained in photo interpretation.

The second project was only 3.1 miles long. In this case the savings is estimated to be $528.00 per linear mile. Again significantly above the costs of engineering soil mapping.

Based on results of this study and reinforced by studies of McKittrick, it is definitely indicated that detailed engineering soils mapping as applied to highway soils investigations could result in large economies. These economies more than cover the cost of the engineering soils mapping itself and, as indicated by the two cases illustrated, would justify the use of color prints for the preparation of annotated master soil plans.

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This research project was concerned with the use of different aerial films, prints and multispectral imagery as a principal source of data for engineering soils mapping. Based on the results obtained for a 70-mile highway project in Indiana, it is concluded that:

1. In terms of developing annotated aerial photographs as detailed engineering soils maps, color photography as opposed to black and white or color infrared photography was found to be the best and most reliable source of information. Natural color allowed the mapping of a greater number of soil types and soil conditions but it did not allow to fully assess all soil conditions. It resulted in more accurate and much faster interpretation.

2. The combined use of color prints and color infrared transparencies was found to be the best combination of two sources of remotely gathered information. This combination enabled us to identify a greater number of soils and evaluate a greater number of soils conditions, like the moisture distribution.

3. For the preparation of detailed engineering soils maps, color photography was found to be a greater asset than soils information obtained from agricultural soils maps and/or detailed geological maps.

4. Multispectral imagery obtained in fifteen bands from ultraviolet (0.32-0.38 micron) to far infrared (8-14 micron region), was found to be a beneficial source of information on soils and soil conditions as a supplement to color areial photography. The major assets of multispectral imagery is to give the spectral signature of the materials remotely studied, and to procure information at different wavelengths unavailable otherwise. It also gives data in a quantitative format with the possibility of quantitative processing.

5. It is concluded that if the multispectral imagery is to be treated automatically by computer, the maximum number of bands possible should be made available. In this manner the automatic classification of terrain features and soils can be based on the optimum set of bands as selected by the computer and is not limited to a pre-set number of bands.

6. If the imagery is to be analyzed by visual means only, it was found that the minimum number of bands should be four and the maximum should be six. The set of four bands includes: the far-infrared (8-14 microns), the reflective infrared (0.8-1.0 micron), the red (at about 0.60 to 0.66 micron) and the green (at about 0.52 to 0.55 micron). The set of six bands should include: the four bands named above, plus the blue (at about 0.40-0.44 micron) and the ultraviolet (at 0.32-0.38 micron). The reason for restricting the number of bands was the inherent limitation of the human capacity to store and analyze many grey toned images of the same area and analyze such a large number of areas.

7. It was found that a much more powerful method of simultaneous examination and interpretation of multispectral imagery is by the use of the automatic classification computer method, as developed at the Purdue University Laboratory for Agriculture Remote Sensing (LARS). The LARS computer programs and methods permitted

a. classification of strips of land surface in terms of vegetation, water and soils. Maps were obtained in this project that distinguished and automatically classified up to seven soil types, through the utilization of this multispectral response signature concept.

b. delineation of unique soil conditions on a single printout map, leaving blank all other materials, thus emphasizing the distribution of adverse soil conditions.

c. the illustrating, for the first time, a relationship between spectral response of a soil and its land form and parent material.

d. the relation on the basis of spectral signature between a type of soil and its source located about a quarter of a mile away.

8. The multispectral imagery limitations as used for engineering soils mapping were the interference of vegetation locally masking the spectral data on soils and the complete lack of information on topography.

9. Laboratory spectral reflectance measurements were found to be useful in studying the major factors affecting spectral reflectance. The major factor controlling reflectance was found to be

the water content.

10. Field thermal radiation measurements over cycles of twenty-four and forty-eight hours indicated significant differences in thermal behavior of earth materials under the different field conditions:

a. Color, moisture, cloud cover and wind appeared to be the most important factors controlling the apparent temperature and the thermal behavior.

b. The peak temperature readings of the materials investigated showed some differences among various materials but not between all of them.

c. Glass thermometers at 1/4 in. depth in the soil differed slightly from the infrared radiometer apparent temperature readings.

d. The infrared radiometer was found to be much more sensitive to variations than the glass thermometers, particularly to variations due to wind or to the presence of clouds.

e. The color of the material was a more important factor than surface texture.

f. It is concluded from these ground measurements that the 8-14 micron region appears to be very useful to detect soils with high moisture content but it does not seem sufficient to help determine the nature of materials by itself.

11. Detailed engineering soils plans and profiles prepared by interpretation of color aerial photographs can be successfully

incorporated in actual engineering soil surveys for highway projects. They can be used to plan better soils investigations and to select borings locations so as to obtain more representative samples. In addition they provide for a better route location and overall planning. The additional expense of using color photographs is shown to be offset by the economies resulting from the use of these detailed maps.

6.2 Recommendations

During the progress of this research project potential applications and possible extensions for research became apparent which were beyond the scope of the current study. They are included in the following recommendations for further study:

1. Additional areas should be investigated using multispectral imagery and the LARS computer classification approach. Other terrains and other soils most particularly in areas of minimum vegetation cover should be considered.

2. The LARS computer method should be used for other engineering purposes than soils mapping such as land use studies and pollution problems. It should be expanded and investigated in greater depth in soils mapping, bedrock mapping and in other types of earth materials surveys.

3. The infrared 8-14 micron data should be collected both during daytime and at night, for future projects. The optimum times appear to be from eleven o'clock to three o'clock during the day and between the pre-dawn hours (2:00 a.m. to 6:00 a.m.).

4. Efforts to calibrate the scanner data should be continued, in order to correlate the multispectral data with ground information, for both the temperature and the reflectance of soils.

5. The use of detailed engineering soils maps prepared from aerial photographs as developed in this research project should be implemented. Because they result in significant savings of money and time in addition to provide for better overall engineering planning, these maps should be incorporated into future highway planning studies and soils surveys.

6. Because of the success of multiband color photography with enhancement techniques in other fields, it is recommended that it be researched for potential engineering applications to soils mapping.

7. Laboratory spectral reflectance studies should be extended to other engineering soils and materials. Field infrared radiometric and reflectance measurements should be collected and analyzed throughout the spectrum from the ultraviolet to the microwave region.

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APPENDIX 1

SUMMARY OF SOIL TESTING DATA

TABLE 14

APPENDIX I SUMMARY OF SOIL TEST DATA

Profile No.	Engineering Soil Map Units	Eng. Soil Map No.	Airphoto Number (1:12000 series)	Land Form and Soil Description (Ag. Soil Series)	Sample No.	Depth / Water T.	Horiz	Moisture-Density: Max Dry Den	Moisture-Density: Optim Moist	Percentage Passing Sieve: 3/4in	3/8in	No.4 4.7 mm	No.10 2.0 mm	No.40 .42 mm	No.60 .25 mm	No.200 .074 mm	Percentage Smaller Than: .05 mm	.02 mm	.005 mm	.002 mm	L.L	P.I.	Classification: AASHO	Unified
P-1	Mk (Mk12g3s)	1. (1.1)	28	Kame moraine - clayey silt over sand and gravel.	S-1	0-16	A	105.6	18.1				100	93	83	66	64	56	37	34	24	5	A-4(6)	CL-ML
					S-2	16-36	B	104	18.9				100	96	90	76	73	64	46	[illegible]	[illegible]	20	A-6(12)	CL
				(Bellefontaine loam)	S-3	36-60	C	116.7	13.3	91	84	74	55	10	5	1					NP		A-1-b(0)	SW
P-2	Mk (Mk12g3s)	1. (1.1)	28	Kame moraine - silty clay over sand and gravel.	S-4	0-6	A	116.4	13.5		100	78	74	75	67	58	57	48	36	33	29	7	A-4(5)	CL-ML
					S-5	6-34	B	93	25				100	98	97	[illegible]	[illegible]	79	48	29	47	24	A-7-6(15)	CL
				(Bellefontaine loam)	As S-3	34-60	C	(as B-3)															A-1-b(0)	SW
P-3	L:S/Rm L4:S3g3s / Rm12g3s	2. (2.3)	54	Loess plain over ridge moraine - coarse clean gravelly sand. (Princeton fine sandy loam)	S-6	12-360	B	115.0	14.0	93	89	82	66	14	6	1					NP		A-1-b(0)	SW
P-4	L:R/ls	3.	76	Loess plain and residual blanketing limestone plain - light brown clay silt.	S-7	0-8	A	97.4	22.5				100	99	98	96	93	78	31	20	38	10	A-4(8)	ML
				(Frederick silt loam)	S-8	8-48	B	100.4	20.9				100	97	96	94	91	77.	37	25	39	14	A-6(10)	ML-CL
P-5	L:R/Ls	3.	76	Loess plain and residual blanketing limestone plain light yellow brown silty clay.	S-9	0-8	A	99.1	21.7				100	99	98	96	93	77	34	23	39	13	A-6(9)	ML
				(Frederick silt loam)	S-10	8038	B	103.3	19.4				100	99	99	98	94	79	40	32	42	17	A-7-6(11)	CL-ML
P-6	L:R/ls	3.	78	Loess plain and residual blanketing limestone plain - reddish yellow brown clay.	S-11	0-6	A	105.8	18.0				100	99	99	98	95	76	40	31	38	14	A-6(10)	CL-ML
					S-12	6-15	B	102.2	19.9				100	99	98	97	94	75	46	26	45	22	A-7-6(14)	CL
				(Frederick silt loam)		15-18	C																A-7-6	CL
P-7	L:R/ls	3.	78	Loess plain and residual blanketing limestone plain - reddish brown clay.		0-12	A																	
					S-13	12-30	B	97.8	22.3				100	99	99	98	95	85	61	54	63	36	A-7-6(20)	CH
				(Bedford silt loam)		30+	C																(A-7-6)	
P-8	Fp (Fp463pf)	3. (3.1)	84	Floodplain - light grey clayey silt.	S-14	0-10	A	105.0	18.4			100	99	98	97	87	84	62	37	30	34	9	A-4(8)	ML
				(Holly silt loam)	S-15	10-52	B	103.8	19.0				100	99	98	96	93	64	37	27	34	13	A-6(9)	CL
P-10	Fp	1.	8	Floodplain - light brown loamy sand.		0-15	A																(A-4, A-6)	
				(Miami loam)		15-36	B																(A-2-4)	
P-11	M	1.	8	Muck.		0-36	A																Muck	
P-12	Fp	1.	10	Floodplain - light yellow brown coarse loamy sand.	S-16	0-10	A							78.4		46.0					16	2	A-4	SM
					S-17	10-30	B							72.0		42.4					21	8	A-4	SC
				(Miami loam)	S-18	30-35	C							59.8		32.4					43	23	A-2-7	SC
P-13	Mk	1.	10	Kame moraine - light rusty brown fine sand.		0-8	A																(A-4)	
				(Miami loam)		8-48	B																(A-4 A-6)	
						48-72	C																(A-2-4)	
P-14	Gd	1.	12	Ground moraine depression - gray clay loam.		0-16	A																(A-4)	
						16-20	B																(A-6)	
				(Miami black clay loam)		20-37	C																(A-2-6)	
P-15	Gd	1.	12	Ground moraine depression - brown clayey sand and gravel.	S-19	0-15	A							65.1		36.7					27	6	A-4	SM-SC
					S-20	15-32	B							66.3		42.9					30	12	A-6	SC
				(Miami loam)	S-21	32-46/36	C							71.2		47.5					41	22	A-6	SC
						46-60	D																(A-2-4)	
P-16	Gd	1.	12	Ground moraine depression - brown clayey sand and gravel.		0-10	A																(A-4)	
						10-21	B																(A-4)	
				(Miami loam)		21-30/28	C																(A-2-4)	
P-17	Mk	1.	14	Kame moraine - dark brown clay loam.		0-22	A																(A-4)	
						22-36	B																(A-4, A-6)	
P-18	M	1.	14	Muck		0-11/2																	Muck	
						11-36																	(A-6, A-7)	
P-19	E	1.	14	Esker - clean sand and minor gravel.		0-14	A																(A-4)	
				(Miami gravelly loam)		14-56	B																(A-2-4)	
						56-84	C																(A-1-b)	
P-20	Fm	1.	14	Minor floodplain - light brown silty sand.		0-28	A																(A-4)	
				(Miami loam)		28-36	B																(A-2-6)	

TABLE 14 cont'd

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Profile No.	Engineering Soil Map Units	Eng. Soil Map No.	Airphoto Number (1:12000 series)	Land Form and Soil Description (Ag. Soil Series)	Sample No.	Depth / Water T.	Horiz.	Moisture-Density: Max. Dry Den.	Moisture-Density: Optim. Moist.	Mechanical Analysis — Percentage Passing Sieve: 3/4in	3/8in	No.4 4.7 mm	No.10 2.0 mm	No.40 .42 mm	No.60 .25 mm	No.200 .074 mm	Percentage Smaller Than: .05 mm	.02 mm	.005 mm	.002 mm	L.L.	P.I.	Classification: AASHO	Unified
P-21	Mk	1.	18	Kame moraine - light brown fine to medium sand.		0-24	A																(A-4)	
						24-40	B																(A- -6)	
				(Fox loam)		40-60	C																(A- -4)	
P-22	Mk	1.	0	Kame moraine - light brown clay sand.		0-14	A																(A-)	
				(Martinsville loam)		14-34	B																(A-2-4)	
P-23	Fp	1.		Floodplain- sand and gravel.	S-22	0-12	A1							88.1		57.1					21	7	A-4	CL-ML
				(Fox loam)	S-23	12-20	A							88.6		54.					21	6	A-4	CL-ML
					S-24	0-46	B																(A-4)	
					S-25	46-66	C					8 .4		59.6		12.7					NP	NP	A-1-b	SM-SW
P-24	Fp	1.	20	Floodplain Depression - dark gray organic clay loam.		0-20	A																(A-4 A-6)	
				(Westland silty clay loam)		20-27	B																(A-6)	
P-25	Mk (Mk12g3s)	1. (1.1)	22	Kame moraine - sand and gravel.		0-9	A																(A-4)	
				(Princeton fine sandy loam)		9-42	B																(A-4 A-6)	
						42-48	C																(A-2-4)	
						48-84	D																(A-1-b)	
P-26	Fm (Fm24i3m)	1. (1.1)	22	Minor floodplain - medium brown silty clay.	S-26	0-6	A1							90.6		57.3					21	7	A-4	CL-ML
				(Eel silt loam)		6-23	A2																(A-4)	
						23-33	B																(A-6)	
P-27	Mk (Ok24613m)	1. (1.1)	24	Kame moraine - medium gray organic clay.	S-27	0-8	A							98.7		97.4					31	9	A-4	CL
				(Fox loam)	S-28	8-38/36	B							99.8		99.8					31	13	A-6	CL
					S-29	36-75	C							99.7		95.2					45	21	A-7	CL
P-28	Mk (Kig3d)	1. (1.1)	24	Kame moraine - sand and gravel. (Fox loam)	S-30	0-16	A					86.4		47.1		18.4					17	4	A-2-4	SM-SC
P-29	Mk (Mk12g3s)	1. (1.1)	26	Kame moraine - silty clay over clayey sands and gravels	S-31	0-12	A							85.0		66.3					22	5	A-4	CL-ML
				(Brookston silt clay loam)	S-32	12-30	B1							93.0		77.8					39	21	A-6	CL
						30-40	B2																(A-2-4)	
						40-48	C																(A-1-b)	
P-30	Fp (Fp24113f)	2. (2.1)	32	Floodplain - medium brown sandy clay loam.	S-33	0-15	A							93.6		58.0					23	7	A-4	CL-ML
				(Whitaker fine sandy loam)	S-34	15-28	B							80.3		62.8					33	12	A-6	CL
					S-35	28-42	C					89.2		61.4		43.2					38	17	A-6	CL
P-31	Fp (Fp24113f)	2. (2.1)	34	Floodplain - light brown silty clay loam.	S-36	0-14	A							99.1		89.7					31	10	A-4	CL
				(Genessee loam)		14-28	B																(A-6)	
P-32	Fp (Fp241p3f)	2. (2.1)	34	Floodplain - light brown silt.	S-37	0-14	A							98.2		90.8					34	13	A-6	CL
				(Eel silt loam)		14-30	B																(A-6)	
					S-38	30-80	C							86.9		32.1					18	4	A-2-4	SM-SC
P-33	Fp (Fp24113f)	2. (2.1)	34	Floodplain - light yellow sand.	S-39	0-8	A							97.1		84.7					38	18	A-6	CL
				(Genessee fine sandy loam)	S-40	8-36	B							86.9		24.9					15	1	A-2-4	SM
					S-41	36-60	C							95.0		17.4					NP	NP	A-3	SM
P-34	Fs (Fs46/12p3f)	2. (2.2)	38	Floodplain depression - medium brown clay loam.	S-42	0-14	A							83.7		42.5					18	3	A-4	SM
				(Fox loam slp. phase)		14-24	B																(A-6)	
P-35	Fp ($T_1$23/12g3f)	2. (2.2)	38	Floodplain lower terrace - sand minor gravel.	S-43	0-8	A							99.3		91.7					39	16	A-6	CL
				(Fox fine sandy loam)		8-16	B																(A-2-4)	
P-36	Fp (Fp2113f)	2. (2.2)	40	Floodplain light brown silt.	S-44	0-12	A							98.4		88.4					37	16	A-6	CL
				(Eel silty clay loam)		12-32/36	B																(A-6)	
P-37	Fp	2.	40	Floodplain medium gray brown clay loam.	S-45	0-12	A							98.6		84.5					39	16	A-6	CL
				(Genessee silt loam)		12-30	B																(A-6)	
P-38	L:B/Rm	2.	42	Loess plain over ridge moraine - yellow brown sandy silty clay.	S-46	0-15	A							96.2		72.3					41	24	A-7	CL
					S-47	15-48	B																A-6	CL
				(Gibson silt loam)	S-48	48-76	C							96.8		93.4					41	21	A-7	CL

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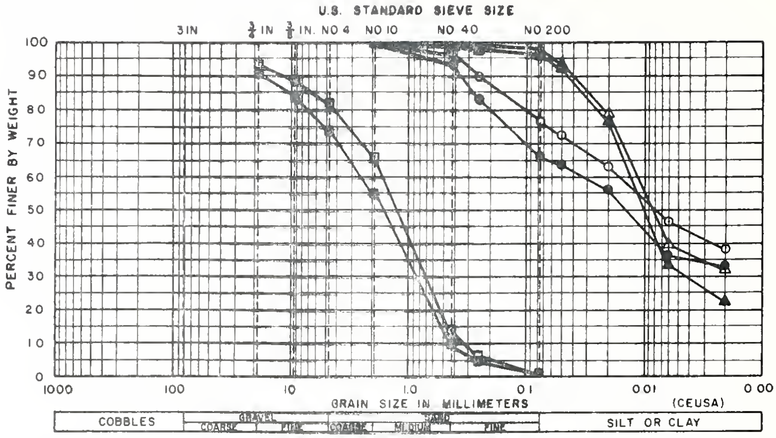
[illegible]	L:S/Rm	[illegible].	52	Loess plain over ridge moraine - brown red sandy silty clay.		0-18	A																(A-4)	
						18-60	B																(A-6)	
				(Cincinnati silt loam)	S-59	60-86	C					97.6		85.0		62.6					33	17	A-6	CL
[illegible]	L:S/Rm (S?g)	[illegible]. (2.3)	54	Loess plain over ridge moraine - reddish yellow silty sand. (Princeton fine sandy loam)		0-15	A					68.4		33.1		24.0					30	11	A-2-6	SC
						15-72	B																(A-2-6)	
[illegible]	L:S/Rm (S?g?)	2. (2.3)	54	Loess plain over ridge moraine - medium yellow brown sand.	S-52	0-8	A							90.1		16.5					NP	NP	A-[illegible]	SM
						8-16	B																(A-2-4)	
				(Princeton fine sandy loam)		16-72	C																(A-[illegible])	
P-42	L:S/Rm (S?g?)	2. (2.3)	54	Loess plain over ridge moraine - light brown silty sand.	S-53	0-6	A					39.1		87.0		29.6					NP	NP	A-3	SM
						6-22	B																(A-2-4)	
				(Princeton fine sandy loam)		22-X	C																(A-2-4)	
P-43	Lc/Ow (Lc68p f Ow?1 f)	2. (2.3)	56	Lacustrine plain over outwash plain - organic silty clay.	S-54	0-12	A																A-6	CL
					S-55	12-27/27								88.6		94.9					36	17	A-6	CL
				(Maholasville loam)	S-56	27-48	C							89.5		53.3					43	31	A-7	CL
P-44	Lc/Ow Ow 61 f	2. (2.3)	56	Lacustrine plain over outwash plain - gray yellow sand.	S-57	0-12	A							90.8		18.8					NP	NP	A-3	SM
				(Whitaker loam)	S-58	12-52/36	B							77.[illegible]		28.5					22	6	A-2-4	SM-SC
						52-72	C																(A-4)	
P-45	C	2.	58	Colluvial slope - yellow brown sandy silt.		0-12	A																(A-4)	
						12-24	B																(A-6)	
				(Bellefontaine loam)		24-60	C																(A-2-6)	
P-46	L:R/Sh	2.	58	Loess plain and residual soil blanketing siltstone plain - yellow brown sandy silt. (Bellefontaine loam)		0-12	A																(A-4)	
						12-24	B																(A-6)	
						24-[illegible]	C																(A-2-6)	
P-47	Pp/Ow	2.	58	Floodplain over outwash plain - light yellow silt. ([illegible]el silt loam)		0-11	A																(A-4)	
						11-	B																(A-4 A-6)	
P-48	Fp	[illegible].	64	Floodplain - yellow brown silt.		0-8	A																(A-4)	
				(F[illegible] silt loam)		8-[illegible]4	B																(A-6)	
[illegible]	L:R/Sh	2.	64	Loess and residual plain over siltstone plain - yellow brown fine sand.		0-12	A																(A-4)	
						12-24	B																(A-4 A-6)	
				(Muskingum silt loam)		24-[illegible]6	C																(A-2-6)	
P-50	R/Ls	3.	60	Residual soil blanketing limestone plain - red clay.		0-12	A																(A-6)	
				(Bedford silt loam)		12-28	B																(A-6)	
						28-56	C																(A-7-6)	
						56+	D																(A-7-6	

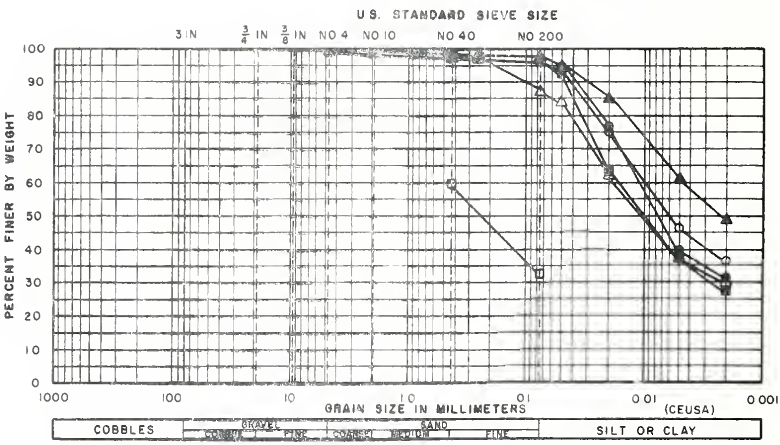
Notes:

1. For the engineering soil map units of column two, refer to the legend preceding the maps.
2. The numbers in column three refer to the engineering soil map number, as it appears at the bottom of each map.
3. The photo numbers of column four refer to an early set of photos at 1:12000 taken on April 11 1967.
4. The soil description in the fifth column refers to the "C" horizon when it is available as indicated in the eighth column; if not available then it applies to the "B" horizon.
5. In column seven (Depth/Water Table), the underlined numbers designate the bottom depth of the hole (all borings were by hand auger). The numbers below a slanted line designate the depth at which water table was encountered. The first eight profiles were sampled in December (Dec. 10, 67). The others were sampled in the Spring (April-11-68 April-27-68 April-28-68 and [illegible]-68).
6. The testing methods followed in this classification of soil sample were the standard AASHO methods.
7. When the AASHO classification in column [illegible] appears in parentheses, this indicates that it is an estimated classification based on field indications not on laboratory testing



BORING NO	DEPTH	CLASSIFICATION	NWC	LL	PL	PI	AASHO	USCS
● S-1	0-16 IN	MEDIUM BROWN CLAYEY SILT		24	19	5	A-4(6)	CL-ML
○ S-2	16-36 IN.	YELLOW BROWN SILTY CLAY		39	19	20	A-6(12)	CL
■ S-3	36-60 IN.	WELL GRADED COARSE SAND		NP	NP	NP	A-1-6(0)	SW
□ S-6	12-36 IN	WELL GRADED COARSE SAND		NP	NP	NP	A-1-6(0)	SW
▲ S-9	0-8 IN	LIGHT BROWN SILT		39	26	13	A-6(9)	ML
△ S-10	8-38 IN.	YELLOW BROWN SILTY CLAY		42	25	17	A-7-6(11)	CL-ML

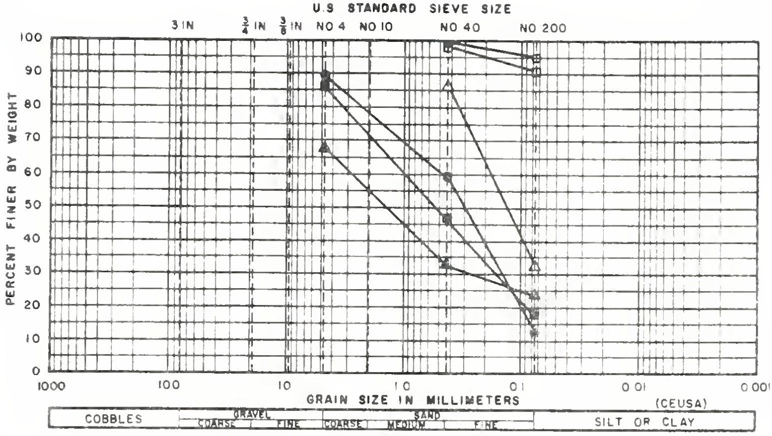
GRADATION CURVES



BORING NO	DEPTH	CLASSIFICATION	NWC	LL	PL	PI	AASHO	USCS
● S-11	0-6 IN	LIGHT BROWN CLAYEY SILT		38	24	14	A-6(10)	CL-ML
○ S-12	6-15 IN	LIGHT REDDISH BROWN CLAY		45	23	22	A-7-6(14)	CL
▲ S-13	12-30 IN.	RED CLAY		63	27	36	A-7-6(20)	CH
△ S-14	0-10 IN	LIGHT YELLOW GREY SILT		34	25	9	A-4(8)	ML
■ S-15	10-52 IN	LIGHT GREY SILT		34	21	13	A-6(9)	CL
□ S-18	30-35 IN	BROWN YELLOW CLAYEY SAND		43	20	23	A-2-7	SC

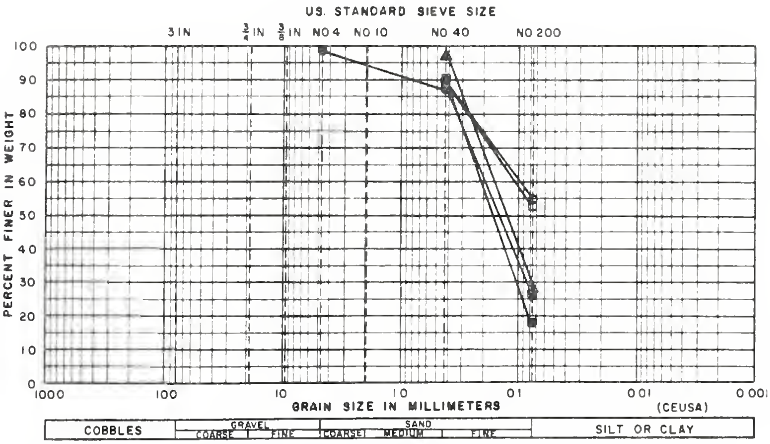
GRADATION CURVES

FIGURE 92. GRADATION CURVES



BORING NO	DEPTH	CLASSIFICATION	NWC	LL	PL	PI	AASHO	USCS
● S-25-A	46-66 IN	SILTY SAND - GRAVEL		21	14	7	A-1-B	SW-SM
○ S-29	36-75 IN	GREY CLAY (ORGANIC)		45	24	21	A-7	CL
■ S-30	0-16 IN	COARSE SILTY SAND		17	13	4	A-2-4	SM-SC
□ S-37	0-14 IN.	DARK BROWN SILTY CLAY		34	21	13	A-6	CL
△ S-38	30-80 IN	LIGHT BROWN SILTY SAND		18	14	4	A-2-4	SM-SC
▲ S-51-A	0-15 IN	COARSE SILTY SAND		30	19	11	A-2-6	SC

GRADATION CURVES



BORING NO	DEPTH	CLASSIFICATION	NWC	LL	PL	PI	AASHO	USCS
● S-53	0-6 IN.	DARK GREY SAND		NP	NP	NP	A-3	SM
○ S-55	12-27 IN.	GREY CLAY (ORGANIC)		36	19	17	A-6	CL
□ S-56	27-38 IN.	GREY CLAY (ORGANIC)		43	12	31	A-7	CL
■ S-57	0-12 IN	BROWN YELLOW SAND		NP	NP	NP	A-3	SM
▲ S-58	12-52 IN.	GREY YELLOW SILTY SAND		22	16	6	A-2-6	SM-SC

GRADATION CURVES

FIGURE 93. GRADATION CURVES

APPENDIX 2

DESCRIPTION OF TEST SITES

APPENDIX 2

DESCRIPTION OF TEST SITES

A total of 28 test sites (or stations) were selected along Highway 37, to carry radiometer measurements investigations. These test sites were selected on the following basis: (1) bare soil or bare rock; (2) surface free of other materials or of vegetation; (3) relatively flat; (4) easy of access; (5) representative of the typical materials of the area; (6) maximum size possible, as this was a problem for the rock outcrops.

The description of these test sites is presented in a table form with a road log starting 0.0 mile from the intersection of I465 and State Route 37 going south, and with a description of the site, the material and instrumentation. The description of each site is as of April 28, 1967. It is based on the author's field notes and color diapositites taken on that date.

TABLE 15

TEST SITES DESCRIPTION

Test Site No.	Route Mileage and Location	Description (April 18, 1967)	Instrumentation
1	11.4 Field on North-West side of intersection, at top of road cut.	Kame moraine with thin silt cover; planted in clover; no growth showing; relatively humid at upper ½ inch (17.9%) around 11:00 AM	3 glass thermometers at surface, at ½ inch, at 4 inches deep.
2	same field.	Same; soil humidity at ½ inch (14.3%).	2 glass thermometers at ½ and 4 inches.
3	same field.	Same; soil humidity at ½ inch (14.5%).	2 glass thermometers at ½ and 4 inches.
4	same field.	Same; soil humidity at ½ inch (19.1%).	2 glass thermometers at ½ and 4 inches.
5	same field.	Same; soil humidity at ½ inch (16.4%).	2 glass thermometers at ½ and 4 inches.
6	23.0 North-East side of intersection of S.R. 252 and the new by-pass at Martinsville.	Kame moraine: sand and gravel in road cut; dry surface (1.6%) no vegetation.	2 glass thermometers at ½ and 4 inches.
7	30.0 (Check point: 24.2 mi. at Martinsville Courthouse) road cut (right side).	Borden siltstone road cut; dry unweathered grey surface.	1 glass thermometer at surface covered with small rock fragments.
8	same road cut.	(same.)	(same.)
9	same road cut. (left side)	Borden siltstone road cut; dry surface; weathered to brown yellow color.	1 glass thermometer covered with very small rock fragments.
10	30.6 road cut (left side).	Borden siltstone road cut; dry surface; weathered to yellow brown color.	1 glass thermometer covered with very small rock pieces.
11	30.6 same road cut.	(same.)	(same.)
12	32.5 right hand side of road.	Borden siltstone outcrop; dry surface, slight amount of growing weeds, weathered to yellow buff color.	1 thermometer in shade of station wood stake, ½" above ground.

TABLE 15 (Continued)

Test Site No.	Route Mileage and Location	Description (April 18, 1967)	Instrumentation
13	34.2 field on right hand side of gravel road by the water tower.	Residual soil over limestone; thin loess mantle; highly humid soil (20.8% at ½")	2 glass thermometers at ½ and 4 inches.
14	34.9 left hand side road cut.	Limestone road cut; 12 sq. ft. bare rock surface, clean, highly stained to a grey beige color.	1 glass thermometer in contact with rock surface.
15	35.9 in field behind LePaul station, access via side road.	Residual soil over limestone; thin loess mantle; humid soil at ½" (20.0%) very roughly plowed; minor amount of vegetation.	2 glass thermometers at ½ and 4 inches.
16	same field.	same. (26.0)	same.
17	same field.	same. (26.0)	same.
18	same field.	same. (24.8)	same.
19	36.2 bare soil area on left side of road.	Residual red clay on limestone; humid (15.1%) and of a deep brown red, partly spotted by drier small areas.	2 glass thermometers at ½ and 4 inches.
20	same area.	same. (16.9)	same.
21	same area.	same. (21.3)	same.
22	37.0 rock cut left hand side of road.	Limestone road cut; bare limestone surface; clean of vegetation; stained to yellowish white color.	1 thermometer in contact with rock surface.
23	same.	same.	same.
24	37.0 top of rock cut on right hand side of road.	Residual red clay on Limestone; humid soil surface (19.6%); clear of vegetation; deep brown red clay with minor dryer areas of lighter tones.	2 glass thermometers at ½ and 4 inches.
25 and 26	39.3 low ground on right hand side of road, at intersection.	Flood plain; silty soil; humid (19.0 and 19.6%); free of vegetation; high water table.	2 glass thermometers at ½ and 4 inches for each site.

TABLE 15 (Continued)

Test Site No.	Route Mileage and Location	Description (April 18, 1967)	Instrumentation
27	45.1 limestone quarry on North side of Bloomington.	Limestone; flat surface slightly stained to a grey white tone; pitted surface; minor amount of small rock fragments joints and cracks filled with grass.	1 glass thermometer at rock surface, for each site.

APPENDIX 3

SUMMARY OF WEATHER FOR DATA COLLECTION DAYS

TABLE 16

SUMMARY OF WEATHER FOR DATA COLLECTION DAYS

Date	Air Temp (°F) Max	Air Temp (°F) Min	Precip. (in)	Rel. Hum. (%) Max	Rel. Hum. (%) Min	Wind (a)	Wind (b)	Wind Dir.	Net Solar Rad.*
INDIANAPOLIS WEIR COOK MUNICIPAL AIRPORT									
April 1967									
20	78	57	.55	90	35	23	12.8	SW	550
21	69	50	0	77	47	17	7.9	NW	698
22	73	50	0	86	44	14	7.3	SE	636
23 (x)	74	47	T	75	44	39	16.5	SW	522
24	47	40	T	60	36	32	15.7	SW	413
25 (x)	58	38	0	61	36	29	12.8	NW	648
26	65	40	T	76	46	24	8.6	N	466
27 (x)	66	38	0	96	32	12	5.6	NE	578
28 (x)	66	43	0	71	33	11	6.0	SE	603
29	69	46	0	74	36	16	6.0	NW	563
30	71	51	0	66	27	17	8.1	NW	674
May 1967									
1	74	47	0	74	28	16	7.6	NW	656
2	83	44	0	65	22	22	6.6	NE	697
3	77	55	T	78	45	24	11.5	W	387
4	70	42	0	93	19	29	8.8	W	588
5 (x)	59	37	0	86	26	18	9.6	N	695
6	63	31	0	70	30	12	6.2	SE	676
7	73	43	0	56	27	23	11.2	SE	603
8	75	55	.01	78	54	19	10.8	SW	425
9	70	49	.74	93	55	34	10.1	SW	429
10	58	44	.10	89	62	7	5.0	NE	259
11	60	55	1.14	96	84	15	8.2	NE	128
12	70	55	T	93	55	7	5.0	SE	513
13	74	50	.03	93	50	24	8.8	SE	566
14	82	62	.02	84	58	13	9.2	SW	542
15	78	64	1.97	90	79	18	7.2	E	202
16	71	55	.02	84	55	23	13.1	SW	509
17	56	47	.11	86	67	12	4.9	W	220
18 (x)	67	40	.15	96	43	18	4.6	W	626

(a) fastest mile in MPH
(b) average in MPH
(x) dates of field data collection
* in langleys.

TABLE 16

(Continued)

Date	Air Temp. (°F) Max	Air Temp. (°F) Min	Precip. (in)	Rel. Hum. (%) Max	Rel. Hum. (%) Min	Wind (a)	Wind (b)	Wind Dir.	Net Solar Rad.*
INDIANAPOLIS WEIR COOK MUNICIPAL AIRPORT									
May 1967 (Continued)									
19	54	43	.09	86	61	22	10.9	W	288
20	62	43	.09	89	62	17	7.3	NW	442
21	68	42	0	93	39	14	6.3	NW	728
22	66	45	.25	89	49	10	4.3	S	456
23	67	54	3.13	97	81	17	7.1	N	156
24	64	58	.31	93	78	13	8.1	NE	194
25 (x)	71	56	.28	87	68	17	10.9	N	380
August 1967									
9	89	70	.01	93	68	20	4.0	SW	482
10	80	61	.89	93	69	18	6.6	N	343
11	76	54	0	80	48	8	5.3	NE	624
12	76	54	0	78	56	10	5.0	SE	631
13	80	67	0	87	64	7	4.3	SE	370
PURDUE UNIVERSITY AGRONOMY FARM									
September 1968									
4	85	60	0	100	45	17	6.0	S	55
5	71	62	.08	100	63	14	5.0	NW	166
6	75	48	0	100	66	14	5.0	W	332
7	75	41	0	99	45	10	4.0	S	279

VITA

VITA

Marc G. Tanguay was born February 22, 1938 in Trois Rivieres, Province of Quebec, Canada. He attended the public school of St. Eustache and completed his high school and college education in the private college "Seminaire de St. Therese," where he obtained a B.A. degree in 1958.

He obtained his Bachelor of Geological Engineering degree in the spring of 1962, from Ecole Polytechnique of Montreal, the engineering school of the University of Montreal. He received his Master's degree in the fall of 1963 from the same engineering school.

In the summers of 1959 to 1961, he worked for the Quebec Department of Mines as junior geologist in several parts of the province; the Noranda mining district and also south of James Bay, the Lake St. John area and the Ungava Nickel Belt, north of the New Quebec Crater.

During the school years of 1961-62 and 1962-63, he taught elementary geology, while completing the requirements for his bachelor and master's degrees. In the summer of 1962, he worked for five months in a columbium mine, as mine geologist. For the school years of 1963-64 and 1964-65, he was instructor at Ecole Polytechnique and taught mineralogy and physical geology to engineering students. He worked during the summers of 1964 and 1965 for the Quebec Hydro Power Commission on dam site selection on rivers east of Seven Islands, Quebec, and on problems of aggregate production and river erosion. In the fall of 1965, he obtained a three-year leave of absence from Ecole Polytechnique to attend Purdue University and

complete his education in Engineering Geology and fulfill the requirements for a Ph.D. degree. In 1965, he received a fellowship from the Canadian Good Roads Association and in 1966, one from Franki of Canada Ltd.

Marc G. Tanguay is a registered engineer in the Province of Quebec and a member of the Canadian Institute of Mining and Metallurgy, the Mineralogical Association of Canada, the Geological Association of Canada. He is also a member of the Geological Society of America, associate member of the Association of Engineering Geologists, student member of the American Society for Testing of Materials, the Highway Research Board, the American Society of Photogrammetry and the American Institute of Mining Engineering.

Marc G. Tanguay is a citizen of Canada and has been a resident of the United States of America for three and a half years. He is married and the father of two children.